BIOFUELS and FOOD SECURITY

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BIOFUELS and FOOD SECURITY

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Land Use Change and Agriculture Program
International Institute for Applied Systems Analysis

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OPEC Fund for International Development (OFID)
and has been prepared by the
International Institute for Applied Systems Analysis (IIASA)

Foreword

by Suleiman Jasir Al-Herbish, Director-General, OFID

Biofuels development has received increased attention in recent times as a means to mitigate climate change, alleviate global energy concerns and foster rural development. Its perceived importance in these three areas has seen biofuels feature prominently on the international agenda. Nevertheless, the rapid growth of biofuels production has raised many concerns among experts worldwide, in particular with regard to sustainability issues and the threat posed to food security. The UN Secretary General, in his opening remarks to the High-level Segment of the 16th session of the UN Commission on Sustainable Development, stated that: "We need to ensure that policies promoting biofuels are consistent with maintaining food security and achieving sustainable development goals".

Aware of a lack of integrated scientific analysis, OFID has commissioned this study, *Biofuels and Food Security,* which has been prepared by the renowned International Institute for Applied Systems Analysis (IIASA). This seminal research work assesses the impact on developing countries of wide-scale production and use of biofuels, in terms of both sustainable agriculture and food security. The unique feature of this study is that its quantified findings are derived from a scenario approach based on a peer reviewed modelling framework, which has contributed to the work of many scientific fora such as the Intergovernmental Panel on Climate Change (IPCC), and the United Nations (Climate Change and Agricultural Vulnerability, World Summit on Sustainable Development, Johannesburg).

One of the key conclusions of the study is that an accelerated growth of first-generation biofuels production is threatening the availability of adequate food supplies for humans, by diverting land, water and other resources away from food and feed crops. Meanwhile, the 'green' contribution of biofuels is seen as deceptive, with mainly second-generation biofuels appearing to offer interesting prospects. Sustainability issues (social, economic and environmental), the impact on land use, as well as many risk aspects are amongst the key issues tackled in the research.

With the publication of this study, OFID seeks to uphold its time-honored tradition of promoting debate on issues of special interest to developing countries, including the OFID/OPEC Member States.

Suleiman Jasir Al-Herbish
Director-General

Foreword

by Professor Detlof von Winterfeldt, Director, IIASA

Scientific evidence has put the world on notice that in the 21st century climate change is a real problem and that further delay of mitigation actions may not only result in substantially higher social costs but may in the long run also put at risk our planet's life supporting capacity. Since the early 1990s, IIASA has investigated multiple dimensions of global change and contributed to assessments of the Intergovernmental Panel on Climate Change (IPCC) by exploring future development pathways and emission scenarios which have become key elements for assessing global future climate change.

The Land Use Change and Agriculture program at IIASA has developed a comprehensive modeling framework to spatially assess the interlinked impacts of climate change and biofuel expansion on agriculture and the world food system. An important first study, commissioned by the United Nations, on agriculture's climate change vulnerability was presented by IIASA at the World Summit on Sustainable Development in Johannesburg in 2002.

The current report on *Biofuels and Food Security* is timely as many developed and developing nations are setting biofuel targets and mandates. Biofuel polices intend to mitigate climate change, enhance energy security and to foster rural development. While the targets are set at national levels their implications go well beyond national boundaries. The results presented in this study highlight the need for coordinated policies and regulation to ensure that efforts made to address climate change and energy security challenges do not exacerbate the pressing problems of food insecurity and environmental degradation.

IIASA's partnership with the OPEC Fund for International Development in preparing this science for policy insight report on biofuels and food security is important for national and international awareness and policy dialogue. Without international cooperation and partnerships we will fail to deal effectively with the emerging global humanitarian, environmental and economic challenges.

Detlof von Winterfeldt
Director

Authors

Günther Fischer is Program Leader at IIASA and his main fields of research are mathematical modeling of ecological-economic systems, econometrics, optimization, applied multi-criteria decision analysis, integrated systems and policy analysis, spatial agro-ecosystems modeling, and climate change impacts and adaptation. He participated in the development of IIASA's world food systems and was a key contributor to several major food and agricultural studies: On welfare implications of trade liberalization in agriculture; on poverty and hunger; and on climate change and world agriculture. He has collaborated with the FAO on the development and application of the AEZ methodology and has contributed to major FAO agricultural perspective studies, to IPCC assessment reports, Millennium Ecosystem Assessment , WSSD Johannesburg Report "Climate Change and Agricultural Vulnerability".

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Harrij van Velthuizen is a land resources ecologist and specialist in agro-ecological zoning. Since 1995 he has been engaged with the activities of the IIASA Land Use Change and Agriculture Program (LUC). With initial support from the Food and Agriculture Organization of the United Nations (FAO), he initiated at IIASA work on global agro-ecological zones assessments, which was published in 2000 and 2002. He is currently engaged in a major update of the LUC-IIASA/FAO global assessment of agriculture potentials and in similar global assessments of bio-mass and biofuels production potentials.

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Acronyms

AoA	Agreement on Agriculture
B100	100 percent biodiesel
B20	20 percent biodiesel and 80 percent diesel
B5	5 percent biodiesel and 95 percent diesel (lower-level blend for use in any diesel engine)
B2	2 percent biodiesel and 98 percent diesel (lower-level blend for use in any diesel engine)
BOD	Biochemical Oxygen Demand
BTL	Biomass to Liquid
CAP	Common Agricultural Policy of the European Union
DDG	Dry Distillers Grain
DDGS	Dried Distillers Grains with Solubles
E100	100 percent ethanol
E85	85 percent ethanol and 15 percent gasoline – can only be used in specially motorized vehicles, such as flexible fuel vehicles (FFVs)
E10	10 percent ethanol and 90 percent gasoline
EBIO	European Biodiesel Board – http://www.ebb-eu.org
EU27	Twenty-seven member states of the European Union: http://europa.eu/abc/european_countries/eu_members/index_en.htm
FAME	Fatty Acid Methyl Esters
FFVs	flexible-fuel vehicles
FAO	Food and Agriculture Organization of the United Nations http://www.fao.org/
FAOSTAT	Food and Agriculture Organization of the United Nations Statistical Database - http://faostat.fao.org/
F-T biodiesel	Fischer-Tropsch biodiesel (advanced option for the production of synthetic biofuels) F-T biodiesel is also often denoted as “Biomass to Liquid” (BTL) transport fuel.
GATT	General Agreement on Tariffs and Trade (1994)
GBEP	Global Bioenergy Partnership – http://www.globalbioenergy.org/
GHG	Greenhouse Gas

GMO	Genetically Modified Organism
GSI	Global Subsidies Initiative – http://www.globalsubsidies.org
Gt	Giga ton
IEA	International Energy Agency – http://www.iea.org/
IIASA	International Institute for Applied Systems Analysis http://www.iiasa.ac.at/
IWMI	International Water Management Institute – http://www.iwmi.cgiar.org/
L	litre
LCA	Life-cycle analysis
LUT	Land Utilization Type
MTBE	Methyl tertiary butyl ether
Mtoe	Million tons oil equivalent
NCGA	National Corn Growing Association (USA)
NPP	Net Primary Production
NUTS 2	Administrative land level unit in the EU
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries – http://www.opec.org/
ProAlcool	Brazilian National Ethanol Program
RED	Renewable Energy Directive (European Commission Communication: *An energy policy for Europe)*
RFS	Renewable Fuels Standard Legislation (USA)
RTFO	Renewable Transport Fuel Order (UK)
Syngas	Synthetic gas produced by thermal gasification of biomass
TAR	Target scenario (see Fig. 3.3-2)
VEETC	Volumetric Ethanol Excise Tax Credit
WDGS	Wet Distillers Grain with Solubles
WEO	World Energy Outlook – http://www.worldenergyoutlook.org/
WTO	World Trade Organization – http://www.wto.org/
WWI	Worldwatch Institute – http://www.worldwatch.org/

Executive Summary

Accumulating scientific evidence has alerted international and national awareness to the urgent need to mitigate climate change. Meanwhile, increasing and reoccurring extreme weather events devastate more and more harvests and livelihoods around the world.

Biofuels have been acclaimed the panacea to reduce greenhouse gas emissions, enhance energy security and foster rural development. The European Union and the United States are both investing heavily in biofuel technologies and support polices, including time-bound targets, to promote biofuels supply and demand. China, India, Indonesia, South Africa and Thailand have also announced targets for development of biofuels.

While these ambitious goals, aimed at enhancing fuel energy security, contributing to climate change mitigation and agricultural rural development offer tempting solutions, nevertheless considerable social, environmental and economic constraints can not be ignored.

As recent events have shown, a number of factors including the adoption of mandatory biofuels policies, high crude oil prices, increasing global food import demand, below average harvests in some countries and low levels of world food stocks resulted in sudden and substantial increases in world food prices. The consequences were food riots around the world from Mexico to Haiti to Mauritania to Egypt to Bangladesh. Estimates indicate that high food prices increased the number of food insecure people by about 100 million.

Despite assertions of the environmental, social and economic benefits of biofuels, there is currently limited scientific research and analysis to support the assumptions driving biofuels developments, particularly with regard to the potential competition between food and feed crops and first-generation biofuels feedstocks.

Second-generation biofuels from ligno-cellulosic feedstocks, which are still very much in the development stage, are less likely to compete for land and water resources with food and feed production than current first-generation biofuels based on food crops.

This study reviews the worldwide status of biofuels development, policy regimes and support measures driving this evolution and quantifies the world-wide agro-ecological potential of first-and second-generation biofuels crops. A comprehensive evaluation is made of the social, environmental and economic impacts and implications of biofuels development on transport fuel security, greenhouse gas emissions, agricultural prices, food security, land use change and sustainable agricultural development.

The rush to biofuels

The world's transport fuel consumption is projected to increase by over 60 percent to some three billion tons oil equivalent in 2030. Developed countries currently account for an estimated 70 percent of world transport fuel consumption but their share is projected to decrease to about 50 percent by 2030.

Current biofuels targets will result in a share of biofuels in transport fuel of 12 percent in the developed countries and of 8 percent in the developing countries by 2030.

Although current indications are that biofuels targets could be reached by 2020, this study shows that caution is needed because first-generation biofuels competing with food crops are not tenable in the long-run. Arable land resources are limited and expansion into forest, grassland and woodland areas will result in significant carbon emissions, negating the primary justification for carbon savings with biofuels.

As long as biofuel expansion is based on first-generation food crops, the speed of biofuel increase must be balanced by increases in overall agricultural productivity. Otherwise biofuel development will result in dire social consequences or harmful environmental impacts.

Will biofuels slow climate change?

Estimated global greenhouse-gas emissions in 2006 amounted to 45 Gt in carbon dioxide equivalent, of which some 62 percent of total global emissions is energy-related. The transport sector globally contributed 6.4 Gt carbon dioxide equivalent in 2006 equal to some 14 percent of total anthropogenic emissions and 23 percent of energy-related emissions.

Carbon losses due to land use change occur at the time of land conversion, but greenhouse gas savings from biofuels use substituting fossil oil accumulate only gradually over time. As a consequence, net greenhouse gas savings, resulting from rapid expansion of first-generation biofuels, will only be reached after several decades. For shorter periods until 2030, the net greenhouse gas balance is dominated by carbon debts due to direct and indirect land use changes.

Even for the period 2000-2050, estimated cumulated gains of 15 to 27 Gt carbon dioxide equivalent need to be put in perspective to current annual greenhouse gas emissions of about 6 Gt carbon dioxide equivalent caused by the transport sector.

A factor in rising hunger

In 1970 about 900 million people in developing countries, a third of the total world population, was chronically undernourished. This figure reached about one billion in 2008 with Africa and South Asia being the most affected regions. It is the rural agricultural population whose livelihoods and food security will be affected by food-feed-fuel competition for land and water resources. The current food crop based biofuels are of concern as their development will also exacerbate food insecurity particularly in many of developing countries.

Biofuels targets imply that an additional 140 and 150 million people may be at risk of hunger by 2020. Africa and South Asia will account for over two-thirds of those people most affected. The Millennium Development Goals put a time-bound target to reduce world hunger by half in the period to 2015. First-generation biofuels will exacerbate the tasks of reducing world hunger and it is the poorest of the world population that will bear the brunt of the consequences.

Upward pressure on world food prices

From the late 1970s to the early 1990s, world food prices gradually declined to nearly half and then stagnated until 2002. During the period 2002 to 2007, world food prices increased by some 140 percent due to a number of factors including, increased demand for biofuels feedstocks and rising fuel and fertilizer prices.

Estimates indicate that agricultural prices will rise by 30 percent due to biofuel targets by 2020.

The results indicate that the highest price will be for maize, a major biofuels feedstock in the USA. Maize is a major staple food crop in many developing countries, particularly in Africa. High world market prices as projected for cereals will have serious implications for food security. Accelerated introduction of second-generation biofuels could reduce price effects by half.

In the case of protein feeds, prices decline by 30 to 40 percent. This is caused by biofuels by-products entering the market in large volumes, for example, protein meals and cakes from crushing of oilseeds and starch-based ethanol.

There is a robust relationship between agricultural prices and target share of biofuels in total transport fuel. Biofuels development policies must give serious consideration to food price impacts as higher prices profoundly affect food security.

Some benefits for rural development

The contribution of biofuels development to increasing agriculture value added is some 6-8 percent in the developed countries and only about 3 percent in the developing countries by 2030. Claimed benefits of biofuels to foster rural development cannot rely on feedstock production alone; it will also require the setting up of the entire biofuels production chain.

The findings highlight that the increase in crop and agriculture value-added is relatively small and puts into perspective the scope and the perceived benefits of biofuels to foster rural development.

Absorbing cereal production

Crop production is driven by yield and acreage developments. In many developing countries crop yields for most commodities are lower than those attained in developed countries. During the period 1970 to 1990 world cereal yields increased on average by 2 percent per annum but since then this growth in yields has halved.

Achieving biofuels targets in 2020 will require additional cereal production of up to 240 million tons. Developing countries account for 75 percent of the implied reduction in cereal food consumption. The results highlight the need to safeguard developing countries against market impacts caused by first-generation biofuel development.

On average about two-thirds of the cereals used for ethanol production are obtained from additional crop production. The remaining one-third comes from consumption changes. The reduction in direct cereal food consumption accounts for ten percent and reduced feed use accounts for about a quarter of the amount of cereals used for biofuel production.

Competition for agricultural land

Some 1.6 billion hectares of land are currently used for crop production, of which 1 billion hectares are under cultivation in the developing countries. During the last 30 years the world's crop area expanded by some 5 million hectares annually, with Latin America alone accounting for 35 percent of this increase.

An additional 27 million hectare in 2020 and 37 million hectare in 2030 would be cultivated to accommodate first-generation biofuels production. About two-thirds of this land expansion occurs in the developing countries. Land conversion for biofuels production will result in greenhouse gas emissions due to carbon losses from soils and vegetation. This needs to be taken explicitly into account in assessing the net greenhouse gas savings with biofuels production. Additional land conversion for biofuels production entails risks for biodiversity.

Fueling deforestation

Forests, in addition to producing timber, wood, fuel, and other products, play an important environmental role in the conservation of biodiversity, wildlife habitats, in the mitigation of global climate change and in the protection of watersheds against soil degradation and flood risks.

Biofuels feedstock production for reaching targets up to 2020 indicates that these may be responsible for deforestation of over 20 million *additional* hectares. In comparison, arable land expansion into forestlands for food production amounts to 50 million hectares by 2020.

Prolonged dependence on first-generation crops for biofuels will result in increased risk of deforestation with the inherent consequences of substantial carbon emissions and loss of biodiversity.

Extensive monitoring of land cover conversion, especially deforestation, is essential. Incentive schemes aiming at avoidance of deforestation should be negotiated at the international level, for example in the context of mechanisms in (post-Kyoto) agreements on combating climate change.

Environmental impact from biofuel feedstock production

There is a wide range of systems and conditions under which biofuels are produced, including different feedstocks used, varying production schemes and management practices, land ownership and land use systems. The impacts of biofuels on biodiversity depend on the extent of land use change and conversion as well as the type of biofuels feedstocks used.

Conversion of natural ecosystems, especially natural forest and natural grassland, generally causes high losses of biodiversity; impacts of using abandoned or degraded agricultural land or low intensity grazing lands are relatively less. The scale of conversion in combination with large-scale mono-cropping without compensating through e.g., “habitat islands”, and “migration corridors” may have a far reaching negative impact on biodiversity.

Nitrogen fertilizer use without biofuels projects an increase of 40 million tons in the period of 2000 to 2030, up from 85 million tons in 2000. Biofuels targets would imply an additional use of about 10 million tons of nitrogen fertilizer, i.e., a 25 percent increase over projected growth without demand for first-generation biofuel feedstocks. As a consequence, about 8 percent more nitrogen fertilizers would be applied in 2030.

Intensive use of fertilizers in biofuels production results in higher greenhouse gas emissions and impacts on other environmental factors such as water pollution. An early transition to second-generation biofuels would result in reduced application of fertilizers.

Imperative for second-generation conversion technologies

In the long run current first-generation biofuels production on cultivated land is not tenable as the world’s limited arable land resources are essential to meet future food demand. Hence it is important to make a fast transition to producing second-generation biofuels from lignocellulosic feedstocks such as perennial grasses and tree species.

Biomass residues from agricultural crops and forestry form a feedstock source as well. However, careful planning and comprehensive policies are required as these biomass feedstocks are often the main source of local household energy for rural populations in many developing countries.

The key challenge for commercial second-generation biofuels is to develop conversion technologies at industrial scale and at competitive prices. These technologies, still at the laboratory experimentation and demonstration stage, require large scale feedstock supplies and pose logistical and sustainable management challenges.

The agro-ecological assessment results in this study indicate a substantial potential for producing lignocellulosic feedstocks on currently unprotected grassland and woodlands. Of the world’s 4.6 billion hectares of grasslands and woodlands about 10 percent is legally protected and some 50 percent is very low productive (tundra, arid lands) or steeply sloped. Over two-thirds of the remaining 1.75 billion hectares grassland and woodland potentially suitable for biofuels feedstock production is located in developing countries, foremost in Africa and South America.

An important current use of these land resources is livestock grazing. The results of detailed livestock feed energy balances suggests that in year 2000 about 55-60 percent of the estimated grassland biomass was required for animal feeding. This share is about 40 percent in developed countries and on average 65 percent for developing countries. Hence, at current use levels, the land potentially available for bioenergy production was estimated in the order of 700 – 800 million hectares, characterized by a rather wide range of productivity levels.

Results indicate that production of lignocellulosic feedstocks on 125 million hectares would be sufficient to fulfill the biofuels target share in world transport fuels. The grasslands and woodlands for biofuels feedstocks production should be selected such that the risks of soil carbon emissions and biodiversity losses are minimized.

Innovative pro-poor partnerships for biofuels

The substantial potential for large scale commercial production of second-generation biofuels feedstocks in tropical grasslands and woodlands areas offers scope and opportunity to develop innovative and mutually beneficial private sector and local community partnerships. The concept here would be for the private sector to invest in land and water resources for biofuels production in combination with food production by and for the local community.

In many instances, private – public partnerships in the past have lead to exploitation of farmers and rural communities. It is critical that legal binding agreements and even international monitoring arrangements be put in place in designing the proposed biofuels private sector – local community partnerships while adhering to principles sustainable environmental practices. The private sector, recognizing its social and corporate responsibility, must commit to making a difference to poverty in the developing world.

Agriculture to be put as priority on the world's development agenda

Agriculture is the dominant user of the environment and natural resources. It has the greatest impact on the sustainability of ecosystems and their services, and accounts directly and indirectly for a major share of employment and livelihoods in rural areas in developing countries. The current trend towards enhancing energy security through biofuels development should trigger parallel efforts to prioritize national and international agricultural development agendas.

Biofuels developments cut across several different policy domains and play out at multiple geographical scales from local to global.

International cooperation and coordination is indispensable for all aspects of biofuels development: to achieve resource-efficient geographical patterns of biofuels production; to optimize environmental protection and reduce greenhouse gas emissions and to create an international environment promoting investments, technology transfers and adoption of best practices.

There have been countless debates on the ethics of feeding cereals to livestock in a world where over one-sixth of the population have to live with chronic undernourishment and debilitating poverty. The risk exists that the next debate will be on the fallacy of feeding cereals to cars! This time, though, the situation is different as the entire world's population will be affected if we fail to deal with the challenges of providing clean energy, ensuring food security and coping with climate change, all of which are interrelated and need to be tackled together.

The way forward for biofuels

Liquid biofuels for transport have been strongly acclaimed and heavily criticized recently for their potential to benefit society as well as the considerable risks their expansion may pose to food security and environmental sustainability. There is a critical need to avoid pitfalls due to hasty biofuels development and to ensure that biofuels contribute to broad-based rural and agricultural development. Even then, liquid transport biofuels can be expected to make only a relatively small contribution to total energy supplies and are only one among many sources of renewable energy. Their efficiency and societal value needs to be assessed vis-à-vis other current and future energy options in the context of comprehensive national and global energy strategies.

Part I: **Introduction**

1.1 Biofuels development challenges

Biofuels development has received increased attention in recent times as cleaner and cheaper transport fuel supplement towards mitigating climate change, expanding the fuel energy resource mix and fostering rural development. This perceived importance in these three areas has seen biofuels feature prominently on the international agenda. Nevertheless, the rapid growth of biofuels production has raised many concerns with regard to implications for food security and environmental sustainability.

Transport fuels account for about a fifth of anthropogenic carbon dioxide emissions and a similar amount is emitted from agriculture and land use changes, particularly deforestation. The transport sector is a critical segment of the socio-economy as it enhances societal cohesion through human mobility and it contributes to economic growth through effective and efficient movement of goods and services.

The rapid expansion of ethanol and biodiesel production from agricultural crops has been affecting virtually all aspects of food markets, ranging from the allocation of land to produce biofuels to the adoption of crop export bans and import restrictions to protect domestic food markets. With more food grains and vegetable oil crops being used to produce biofuels, world food stocks were affected and world food prices increased.

Scientific evidence has put the world on notice that in the 21st century climate change is for real and that further delay of mitigation actions will not only result in substantially higher costs but may in the long run also put at risk our planet's life supporting capacity.

While the world's climate varies naturally as a result of interactions between the ocean and the atmosphere, changes in the earth's orbit and fluctuations in energy received from the sun and volcanic eruptions, human activities – fossil fuel burning and deforestation – are the major source of greenhouse gas emissions and global warming.

Climate change is a consequence of the atmospheric accumulation of greenhouse gas emissions, particularly carbon dioxide. At present global carbon dioxide emissions amount to some 33 billion tons and about 80 percent of this originates from fossil fuel burning. Over the next half century world transport fuel consumption is projected to more than double and there is an urgent need to develop cleaner fuels and improve energy efficiency measures and adopt conservation practices.

A number of developed and developing countries have embraced the apparent win-win opportunity to foster the development of biofuels in order to respond to the threats of climate change, to lessen their dependency on oil and to contribute to enhancing agriculture and rural development. The latter is of particular concern to developing countries where more than 70 percent of the poor reside in rural areas.

Brazil has the longest standing biofuels development program based on ethanol from sugar cane. The program began in earnest in the 1970s with government support incentives, which were successfully dismantled in about 2000 following the privatization of the industry. More recently, member countries of the OECD, notably the USA and some EU countries, have been at the forefront of adopting biofuels development policies including substantial public funding and mandatory time-bound targets. A number of developing countries such as China, India, Indonesia and Thailand have also set targets for biofuels use.

The commercial agriculture sector has embraced this opportunity of assured long-term government support for biofuels and responded with investments and efforts to increase production to meet the market demand for biofuels feedstocks. This has resulted in increased national and world market prices of current fist generation biofuels feedstocks which are also important food and feed crops. The biofuels targets have been set at national and regional levels but their impacts go well beyond national boundaries with regard to food security, energy security and environmental sustainability.

The increasing interest in biofuels has resulted in a situation whereby some countries and major private sector corporations are exploring and entering into leasing land agreements for biofuels production in resource-rich tropical countries such as Ethiopia, Tanzania, Mozambique, Brazil and Indonesia to produce biofuels for the export markets. These arrangements raise a number of concerns with regard to food security. Not only will food exports from the major developed countries be reduced (as they divert land resources to biofuels production) but developing countries endowed with arable resources and food production potential may find it more lucrative to grow and export biofuels feedstocks to developed country markets at the expense of food production for their own consumption and for regional markets.

The rather impetuous policy and public funding and support policy commitments for biofuels development have been expedited without due diligence and comprehensive assessment of the proclaimed scope and levels of greenhouse gas savings from biofuels use as well as the enhancing transport fuel security. There has been a lack of comprehensive assessments, including through analyses of the potential impacts of biofuels developments on international food prices, food security, greenhouse gas savings as well as risks of biodiversity loss.

The year 2008 will perhaps be remembered as the defining moment when the world experienced the reality of the inter-linkages and interdependencies between food and energy. A number of factors including the adoption of mandatory biofuels policies, high crude oil price volatility, increasing food import demand from major developing countries and below average harvests in some countries as well as low level of world food stocks resulted in sudden increases in world food prices causing domestic prices of staple foods in a number of countries to increase by over 50 percent in a matter of weeks.

The consequences were food riots in several developing countries around the world from Mexico to Haiti to Mauritania to Egypt to Bangladesh. Estimates indicate that high food prices increased the number of food insecure people in the world by about 100 million. In the developed countries higher food prices do not significantly impact on food consumption as consumers spend on average less than 15 percent of their household budget on food. In contrast consumers in many developing countries spend 50 to 80 percent of their income on food and higher food prices often result in proportionally reduced consumption and impaired levels of nutrition.

1.2 Food security and sustainable agriculture

During the last four decades up to a fifth of the world population has been chronically undernourished in spite of the fact that at the global level food production has been sufficient to meet everyone's needs. Today some 15 million people die annually from hunger and over 200 million suffer health consequences due to nutritional deficiencies including lack of proteins, micronutrients and essential amino acids.

At the Millennium Summit in September 2000 the largest gathering of world leaders in history adopted the UN Millennium Declaration, committing their nations to a new global partnership setting out a series of time-bound Millennium Development Goals addressing the major and persistent issues of hunger, poverty and health and the need to protect natural resources and ensure environmental sustainability. While these concerns have been on the world development agenda for over half a century and political leaders and policy makers have repeatedly endorsed resolutions to combat these critical humanitarian and environmental problems, sadly the world community has failed to mobilize the resource and policy commitments and concerted implementation actions, both at national and international levels.

The Millennium Development Goal of reducing world hunger by half by 2015 is highly unlikely to be met in many developing countries, particularly in sub-Saharan Africa. There is no way of tackling food insecurity without first addressing the issues of sustainable agriculture and rural development especially since over 70 percent of world's food insecure population is found in the rural areas. This will require the highest policy and resource commitment to achieve sustainable agricultural development.

Historically agriculture has been the foundation of economic growth and prosperity in most developed countries. Today less than 5 percent of the populations in many developed countries derive their livelihoods from farming and yet the agriculture lobby remains politically powerful in Washington, Brussels and Tokyo. In contrast, in many developing countries the majority of the population is dependent on agriculture and yet it often has little political influence.

The trends over the last three decades show reduced allocation of national development budgets to agriculture in many developing countries. This together with declining multilateral lending and bilateral aid for the sector exemplifies the fact that agriculture has been regarded as "backward" and low priority. The reality is that there can be no progress on reducing hunger and poverty without political and resource commitment to agricultural and rural development.

Some 1.6 billion hectares (ha) of land are used for crop production, with about 1 billion ha under cultivation in the developing countries. During the last 30 years the world's crop area expanded by some 5 million ha annually, with Latin America alone accounting for 35 percent of this increase. About 40 percent of the world's arable land is degraded to some degree. Many of the most degraded soils are found in the world's poorest countries; in densely populated, rain-fed farming areas, where overgrazing, deforestation, and inappropriate use compound the problems. When soils become infertile, traditional farmers try to let the land lie fallow until it recovers. If this fails, farmers simply abandon unproductive lands and move on; clearing forests and other fragile land areas as available.

In many developing countries, the need for food for an increasing population is threatening natural resources as people strive to get the most out of land already in production or push into virgin territory to develop more agricultural land (Shah, et al, 2005). The damage inflicted on the environment is increasingly evident: arable lands lost to erosion, salinity, desertification, and urban spread; disappearing forests and loss of biodiversity; and emerging water scarcity. This situation will be further exacerbated by climate change as well as extreme weather events and climate variability that are increasing in frequency and severity. All this will further increase the social, economic and environmental vulnerability of large proportions of the population of developing countries.

World crop production grew by 2.2 percent per year in the 1990s, of which yield increases contributed three-quarters. The balance came from area expansion and more intensive cropping. Increased mineral fertilizer use, mainly in the developing countries, accounted for more than one-third of the growth in cereal production. The need to intensify production to meet the demands of a growing population must not ignore the threat of chemical pollution, especially the risk of contaminating water resources.

Two-thirds of the world's population live in areas that receive a quarter of the world's annual rainfall. About 70 percent of the world's fresh water use is accounted by agriculture, a figure that approaches 90 percent in countries that rely extensively on irrigation. Already some 30 developing countries are facing water shortages and by 2050 this number may increase to over 50 countries, a majority in the developing world. This water scarcity together with the degradation of arable land could become a very serious obstacle to increasing food production.

Forests play an important environmental role in the production of timber, wood, fuel, and other products, in the conservation of biodiversity and wildlife habitats, as well as in the mitigation of global climate change and the protection of watersheds against soil degradation and flood risks. About 30 percent of the world's land surface – some 4 billion ha – is under forest ecosystems. Eight countries – Russia, Brazil, Canada, the United States, China, Australia, the Congo, and Indonesia – account for 60 percent of the world's forestland resources. During the past decade, some 127 million ha of forests were cleared, while some 36 million ha were replanted. Africa lost some 53 million ha of forest during this period – primarily from expansion of crop cultivation and for energy supply.

Sustainable agricultural land use must be based on sound agronomic principles but it must also embrace an understanding of the constraints and interactions of other dimensions of agricultural production, including the flexibility to diversify and develop and maintain a broad genetic base to ensure the possibility of rapid response to changing conditions. Land management practices should control the processes of land degradation and their efficiency in this respect will largely govern the sustainability of land use. Furthermore, sustainability will depend on institutional, political, social and economic pressures and structures that can exacerbate environmental problems (Shah, 1992).

Whilst the justification of biofuels targets to enhance fuel energy security and to contribute to climate change mitigation and agricultural rural development is appealing, the reality is complex since the consequences of biofuels developments result in social, environmental and economic impacts, well beyond the national and regional setting of domestic biofuels targets.

This report presents an integrated agro-ecological and socio-economic global assessment of the inter-linkages of emerging biofuels developments, food security, climate change and sustainable agriculture. Following this introduction, Part 2 presents a review of biofuels polices, trends and an agro-ecological assessment of the potential production of first and second-generation biofuels feedstocks. Part 3 presents the results of the World Food System Model analysis with regard to a number of biofuels development scenarios in the context of future socio-economic pathways and climate change. Part 4 concludes with policy recommendations.

Part II: **Overview, Current Status and Global Trends**

2.1 Biofuel types and processing technology

Biofuels include solid, liquid, or gaseous **fuels** that can be produced from biomass material. The biofuels industry currently comprises two distinct sectors - ethanol and biodiesel - that can be blended with fossil gasoline and diesel respectively. Current biofuel production processes rely on first generation conversion pathways based on sugar, starch, or vegetable oil components of feedstocks.

Although biofuels are made from crop plant material, and hence are a renewable source, they may not be as 'green' as they seem. To produce biofuels large amounts of land are required for feedstock cultivation. Irrigation, use of fertilizers, transportation, conversion, and refinery processes all require energy input and emit carbon dioxide. There are a large and growing number of lifecycle analysis studies that suggest that current biofuels save little greenhouse gas, and that production of biofuels may pose a threat to biodiversity and food security.

Ethanol can be produced from any feedstock that contains a high starch or sugar content, such as maize, wheat, sugar cane, and sugar beet, by the fermentation of carbohydrates. Ethanol has traditionally been used for the production of alcohol but is increasingly being used as a blending agent in transport fuels. After fermentation and distillation, bio-ethanol can be mixed with petrol/gasoline in various proportions. Low-level ethanol blends, such as E10 (10 percent ethanol and 90 percent gasoline) can be used in conventional vehicles, while high-level blends, such as E85 (85 percent ethanol and 15 percent gasoline) can only be used in specially motorized vehicles, such as flexible fuel vehicles (FFVs).

Ethanol blending increases octane levels and reduces carbon monoxide emissions. Global ethanol production has doubled since 2000 to 62 million liters in 2007, of which 86 percent is utilized as fuel ethanol. Nearly 90 percent of all bio-ethanol was produced in Brazil and the United States of America from sugar cane and maize feedstocks respectively.

Biodiesel is produced through a chemical process called transesterification of vegetable oils from crop plants such as oil palm, rapeseed, soya bean, and jatropha. The process produces fatty acid methyl esters (FAME); the chemical name for biodiesel and glycerol. Glycerol is a valuable by-product traditionally used in soaps.

When these vegetable oils are heated, their **viscosity** is reduced, enabling them to be used either directly in **diesel engines** or, after chemical processing, for producing **biodiesel.** Biodiesel is used either in blends with diesel, or in its pure form. B20 (20 percent biodiesel/ 80 percent diesel) and lower-level blends, such as B2 (2 percent biodiesel/98 percent diesel) and B5 (5 percent biodiesel/95 percent diesel) can be used in any diesel engine. B100 (pure biodiesel), or other high-level biodiesel blends, have been used in special engines since 1994. In 2006, about 6.5 billion liters of biodiesel were produced worldwide, of which 75 percent was produced in the European Union.

Biofuel first-generation technologies are extensively employed in Brazil (sugar cane for bio-ethanol), the United States of America (maize for bio-ethanol), and the European Union (oilseeds (mainly rapeseed) for biodiesel).

Current biofuel production processes simultaneously produce fuel and significant amounts of by-products and residues. The type and quantity of by-product depends on the biofuel production chain. By-products may serve as valuable livestock feed (e.g. rapeseed cake, soybean meal, or Distillers' Dried Grains with Solubles (DDGS)) and residues, such as straw and husks, that may be returned to the field or used for co-firing. Some by-products are used for further industrial processing into consumer goods. When by-products are used, or are further processed, they are to be credited to the overall biofuel production chain.

Biofuel production from starch, sugar, and vegetable oil can rely on well-established technologies. The rapid deployment of first-generation feedstocks in Europe recently reflects favorable adoption rates of the agricultural sector to feedstock production. Farm technology requires minimum adaptation as farmers can easily integrate energy crops into their food and feed crop rotation patterns. Decentralized processing plants and feedstock production sites have proved to be feasible.

Environmental concerns raised with regard to biofuel production include the high intensity of feedstock cultivation, unregulated deforestation, and the intensive use of fertilizers and pesticides. In addition, crop production and conversion to biofuels requires varying amounts of fossil energy. First-generation pathways reduce greenhouse gas from 'well-to-wheels' in the range of 20–70 percent compared with fossil fuels.

Research continues to identify more efficient conversion processes. New, more efficient second-generation technologies have the potential to expand substantially the feedstock base for biofuel production (e.g., lignocellulosic biomass, non-edible vegetable oils, and algae).

Advanced conversion technologies are in different phases of their development ranging from experimental through to demonstration stage. Two main processes are used: (i) gasification via Fischer-Tropsch synthesis, which produces biodiesel, and (ii) the biochemical route, which applies enzymatic fermentation of lignocellulosic feedstocks for the production of ethanol.

Second-generation technologies are of interest due to their low CO_2 emissions and the possibility of using non-food feedstocks, such as residues and by-products from agriculture and forestry, and from dedicated non-food related feedstocks (e.g. woody and herbaceous plants such as perennial grasses and fast growing tree species). Second-generation biofuels are expected to reduce well-to-wheels CO_2 emissions by a significant amount (70 to more than 100 percent).

However, technological breakthroughs will be needed to reduce the cost of second-generation pathway technologies. In addition, the required scale of operation will be large and there will be substantial transport costs involved in getting the raw materials to the processing facilities. It is estimated that second-generation biofuels may only become commercially available in the next 10 to 20 years.

2.2 Biofuel policy and support regimes

The United States of America, members of the European Union, Japan, Canada, and Australia have been at the forefront of adopting biofuel development policies. A number of developing countries, such as China, India, the Philippines, and Thailand, have also recently set domestic targets for biofuels use.

Brazil has over 30 years experience of developing a successful biofuel program. Initial phases in the 1970s, using substantial public funding, ended with the dismantling of government support during the 1990s. Subsequent privatization enabled independent companies to become the major players in the production of ethanol from sugar cane.

There are a variety of reasons for public support for a biofuels industry and a wide range of different approaches to the type of government support offered. Governments may provide substantial support to biofuels to enable them to compete effectively with conventional gasoline and diesel. Such support may include consumption incentives (fuel tax reductions), production incentives (tax incentives, loan guarantees, and direct subsidy payments), or mandatory consumption requirements.

The OECD's Economic Assessment of Biofuel Support Policies emphasized that biofuels are currently highly dependent on public funding to be viable. In the USA and the European Union, government support for the supply and use of biofuels amounted to US$ 11 billion in 2006, and this is projected to increase to approximately US$ 25 billion per year by 2015. Estimates indicate that biofuel support costs between US$ 960 and US$ 1700 per ton carbon equivalent of greenhouse gas emissions saved. However, these estimates do not account for all of the costs associated with government support for biofuels, such as subsidies to feedstock crop producers, or the wider economic costs associated with the introduction of a mandate for biofuels use.

Government support policies include budgetary measures, either as tax concessions or as direct financial support for biofuel producers, retailers, or users. Blending, or use mandates, require that biofuels represent a minimum share of the transport fuel market and result in increased fuel costs for consumers due to the higher production costs of biofuels. Trade restrictions, mainly in the form of import tariffs, protect the domestic industry from foreign competitors but also impose a cost burden on domestic biofuel users and limit development prospects for alternative suppliers.

A number of studies have highlighted that government support of biofuel production in OECD countries is costly, has limited impact on reducing greenhouse gases and improving energy security, and has a significant impact on world food prices.

The main public support measures for biofuels, and their associated costs, are briefly reviewed below.

Import tariffs

Many countries apply tariffs to imported ethanol, effectively supporting the domestic ethanol industry. The EU, USA, Canada, Switzerland, and Australia all apply import tariffs, although the world's second-largest ethanol producer, Brazil, does not (see Table 2.2-1). Exceptions to import tariffs are commonly available when countries have entered into free trade arrangements. Currently Australia has one of the highest import tariff rates for ethanol in the OECD, although imported ethanol will be eligible for production grants from 2011, offsetting a price differential between domestic and offshore-produced ethanol.

Applied import tariffs on ethanol in selected countries, 2007 Table 2.2 - 1

Country	Applied tariff	Exceptions
Australia	5% + AUD $0.38142/liter	USA, New Zealand
Brazil	None	n.a.
Canada	C $0.0492/liter	Free Trade Association (FTA) partners
European Union	€ 19.2/hectoliter	European Free Trade Association (EFTA) countries, developing countries in Generalized System of Preferences (GSP)
Switzerland	CHF 35 per 100kg	EU, developing countries in GSP
United States of America	2.5% + US $0.54/gallon	FTA partners, Caribbean Basin Initiative (CBI) partners

Source: Steenblick (2007), page 21

Fuel excise tax exemptions

The most common form of industry support for the biofuels industry in the OECD takes the form of reductions to, or exemptions from, the excise tax applied to other transport fuels. The USA was one of the first countries to allow exemptions from fuel excise for ethanol, although the excise exemption was modified in 2004 to an income tax credit due to excessive costs associated with this policy. Within the USA, a number of individual states continue to offer concessions on fuel excise for ethanol production. Concessions for E10 of up to US$ 0.041 per gallon are primarily provided in 'maize belt' states such as Montana, Iowa, and Maine, with other states offering excise concessions on E85 only. In Canada, fuel excise concessions offered by the provinces also 'stack' with federal concessions to produce increased net concessions for ethanol and biodiesel production.

In the EU, fuel excise concessions or exemptions are offered for ethanol in all member countries except the Czech Republic, Finland, Greece, Italy, and Luxemburg. Germany grants excise concessions for E85, but, as it has mandatory ethanol blending requirements, no excise concession is offered for lower blends. All countries in the EU provide fuel excise exemptions or concessions for biodiesel.

Mandates and targets

In addition to the measures above, a number of countries and states have introduced targets and mandates for the use of biofuels (see Table 2.2-2). Most countries that have introduced targets and mandates apply them to 'biofuels' in general, although a number (including the Australian States of New South Wales and Queensland) specify either ethanol and/or biodiesel targets.

Direct production subsidies

Recently, there has been a move in many principal biofuels-producing nations towards volumetric subsidies and/or consumption mandates. From 2004, the USA Federal Government provided an excise credit of US$ 0.51 per gallon of ethanol to fuel blenders. Excise credits of US$ 1.00 per gallon and US$ 0.50 per gallon were also provided for biodiesel produced from agricultural fats and oils, and biodiesel produced from waste oil, respectively. These excise credits are not taxed under corporate revenue. The Government also offers a 'small producer' tax credit, worth US$ 0.10 per gallon, for the first 15 ML of ethanol or biodiesel produced in factories with a capacity of less than 60 ML.

As is the case with fuel excise tax concessions, individual states in the USA also offer volumetric subsidies on ethanol and biodiesel production. In some cases, producer payments are contingent on the fuel being produced from feedstock sourced from the state in question. In Missouri payments are further restricted to companies that are at least 51 percent owned by agricultural producers who are residents of the State and are actively involved in agricultural production.

In Canada, the Federal Government has allocated a $1.5 billion biofuel incentive program that runs over nine years, starting April 1, 2008. The 'ecoENERGY for Biofuels' program provides for the first three years operating incentives to producers for 'renewable alternatives to gasoline' of up to C$ 0.10 per liter and C$ 0.20 per liter for 'renewable alternatives to diesel'. After three years these maximum rates will decline. Production subsidies are less widespread in the EU, with only Latvia and the Czech Republic offering production subsidies for biofuel production.

Investment incentives

A pervasive feature of government support to the biofuels industry is the provision of capital grants, government loans, or government-guaranteed loans for the construction of biofuel facilities. This support is often provided by multiple levels of government within a given jurisdiction, with programs or schemes typically offered at national, state or provincial,

Voluntary and mandatory targets for transport fuels in major countries Table 2.2 - 2

Country/Region	Mandatory, voluntary or indicative target
Australia	At least 350 million liters biofuels by 2010
Canada	5 percent renewable content in gasoline by 2010
EU	5.75 percent by 2010, 10 percent by 2020
Germany	6.25 percent by 2010, 10 percent by 2020
France	7 percent by 2010, 10 percent by 2015, 10 percent by 2020
Japan	0.6 percent of auto fuel by 2010; a goal to reduce fossil oil dependence of transport sector from 98% to 80% by 2030
New Zealand	3.4 percent target for both gasoline and diesel by 2012
United States	12 billion gallons by 2010, rising to 20.5 billion gallons by 2015 and to 36 billion gallons by 2022 (with 16 billion gallons from advanced cellulosic ethanol)
Brazil	Mandatory 25 percent ethanol blend with gasoline; 5 percent biodiesel blend by 2010.
China	2 million tons ethanol by 2010 increasing to 10 million tons by 2020; 0.2 million tons biodiesel by 2010 increasing to 2 million tons by 2020.
India	5 percent ethanol blending in gasoline in 2008, 10 percent as of 2009; indicative target of 20 percent ethanol blending in gasoline and 20 percent biodiesel blending by 2017.
Indonesia	2 percent biofuels in energy mix by 2010, 3 percent by 2015, and 5 percent by 2020.
Thailand	2 percent biodiesel blend by 2008, 10 percent biodiesel blend by 2012; 10 percent ethanol blend by 2012.
South Africa	2 percent of biofuels by 2013

and local government level. Consequently, it is difficult to determine the full extent of support offered to the industry by these means.

A recent international study on levels of government subsidies to the biofuels industry suggested that in countries with federal systems of government, new or established biofuels ventures could be substantially funded by government assistance through 'subsidy stacking', where investors in biofuels plants are able to access multiple sources of public financing assistance. It is not uncommon for biofuel plants in the United States of America to benefit from a combination of municipal-government support, often in the form of free land or utility connections; state-level support, such as tax credits for investment, or economic development grants or loans; and support from federal agencies under various regional development, agricultural or energy programs. While any one investment aid may not be sufficient to trigger development of a new plant, when they are combined with other programs the total value can be significant. For example, in one specific plant examined in the US State of Ohio, more than 60 percent of the plant's capital is being provided by government-intermediated credit or grants.

Canada's Ethanol Expansion Program has addressed this issue through a requirement that total assistance from all levels of government not exceed 50 percent of total project costs, with grant recipients required to disclose all sources of funding before entering into agreement with the government.

While information on capital support for biofuels projects in the European Union is difficult to obtain, the 2007 report '*Biofuels – at what cost?*' states that government support for ethanol and biodiesel in OECD countries includes grants ratios of 15 to 40 percent of total investment costs, with government support covering up to 60 percent of costs in some cases.

In Sweden tax incentives are offered for the construction of new biofuels plants, while in Brazil biofuels plants are subject to reduced levels of industrial tax. China allows tax exemptions for the biofuels industry.

Various forms of government loans are also employed to assist the biofuels industry internationally. In Canada, 'contingent' loans have been made available by government where the requirement for loan repayments is dependent on market conditions. China also provides loan assistance for the development of biofuels plants. In the USA, Canada, Thailand, and Austria government loans have also been made available to encourage increased community and farmer participation in biofuels manufacturing, particularly through the establishment of small- and medium-sized plants.

Support for biofuels distribution infrastructure

A number of countries and jurisdictions have offered grants, tax concessions and/or subsidies for fuel distribution infrastructure upgrades. In the USA, up to 30 percent of the cost of infrastructure upgrades (particularly for the provision of E85-capable infrastructure) is covered by government assistance. France and the United Kingdom also provide capital allowances and grants for facilitating infrastructure upgrades.

A different approach to infrastructure development has been adopted in Sweden, where in 2006, it became compulsory for petrol stations selling in excess of 3000m^3 of fuel per year to also sell renewable fuels. In 2009, all petrol stations selling more than 1000m^3 of fuel per year will also be required to sell renewable fuel. Subsidies of up to 30 percent of investment costs are provided to assist the industry to meet these requirements.

Support for flex-fuel vehicles

A number of countries, including Brazil, the USA, Cyprus, France, Ireland, and Sweden offer various forms of support for the provision of flex-fuel vehicles (FFVs) to the market. In Brazil, tax exemptions are offered for vehicles that are capable of running on higher blends of ethanol. An agreement was also reached with vehicle manufacturers and importers that two-thirds of new vehicles sold from 2007 would be flex-fuel (E85 capable) vehicles. All cars currently sold in Brazil are capable of running on ethanol in blends up to E25.

In Sweden, incentives are offered for FFV use, including reduced registration charges and road taxes, with some cities also offering free parking and waived congestion charges to FFVs. In the USA since 1988, incentives have been offered to vehicle manufacturers for the production of FFVs. Other incentives offered in certain states in the USA include allowing FFVs to use high-occupancy vehicle lanes regardless of how many passengers are in the vehicle, and exemptions from emission testing or motor vehicle inspections.

In the USA, the rationale for incentives for FFV purchase and use was that as more FFVs entered the market, fuel providers would start providing more E85 pumps in service stations. However, this has not occurred and most FFV owners in the USA tend to run their vehicles exclusively on petrol.

Support for research and development

Government support for research and development of biofuels technology is pervasive. Most current research is directed at the development of second-generation fuel technologies, particularly the development of more cost-effective means of producing ethanol from lignocellulosic material. The research focuses on a number of factors in the production process including feedstock technologies, enzyme and preproduction treatments, and the fermentation of lignocellulosic materials for the production of ethanol.

Support for trade

The World Trade Organization (WTO) does not currently have a trade regime specific to biofuels. International trade in biofuels falls, therefore, under the rules of the General Agreement on Tariffs and Trade (GATT 1994), which covers trade in all goods. WTO Agreements such as the Agreement on Agriculture, the Agreement on Technical Barriers to Trade, the Agreement on the Application of Sanitary and Phytosanitary Measures, and the Agreement on Subsidies and Countervailing Measures apply to trade in biofuels. Agricultural products are subject to the GATT and to the general rules of the WTO insofar as the Agreement on Agriculture does not contain derogating provisions.

Key trade-related issues include the classification, for tariff purposes, of biofuel products as agricultural, industrial, or environmental goods; the role of subsidies in increasing production; and the degree of consistency among various domestic measures and WTO standards.

The Harmonized System classification affects how products are characterized under specific WTO Agreements. For example, ethanol is considered an agricultural product and is therefore subject to Annex 1 of the WTO Agreement on Agriculture (AoA). Biodiesel, on the other hand, is considered an industrial product and is therefore not subject to the disciplines of the AoA. Paragraph 31(iii) of the Doha Development Agenda has launched negotiations on "the reduction or, as appropriate, elimination of tariff and non-tariff barriers to environmental goods and services". Some WTO members have suggested that renewable energy products, including ethanol and biodiesel, should be classified as 'environmental goods' and therefore subject to negotiations under the 'Environmental Goods and Services' cluster. (Source: FAO, 2008a; based on FAO, 2007 and GBEP, 2007.)

The discipline of the AoA is based on three pillars: market access, domestic subsidies, and export subsidies. One of the main features of the AoA is that it allows members to pay subsidies in derogation from the Agreement on Subsidies and Countervailing Measures.

2.3 Biofuel development strategies

2.3.1
Global biofuel production and feedstocks

Worldwide, production of biofuels has been growing rapidly over the past few years reaching nearly 80 billion liters (45 Mtoe) in 2008. In comparison, global transport sector fuel use in 2005 was 2182 Mtoe (IEA, 2008a). Ethanol production accounts for approximately 80 percent of biofuel production but the share for biodiesel is rising. Ambitious biofuel development programs are underway worldwide. Although some plans have been put on hold due to volatile feedstock and energy prices, the growth of biofuel investment continues. Today, more than 1000 biofuel plants are operating in 59 countries around the world with a total investment of US$ 6.5 billion (Table 2.3-1). Installed capacity is well above current production volumes especially for biodiesel.

Despite the ambitious targets in many countries, biofuel production is highly concentrated (Table 2.3-2). The USA and Brazil

Number and capacity of biofuel plants around the world Table 2.3 - 1

	Number of plants	Total capacity *Billion liters*	*Metric tones [million]*	*[Mtoe]*
Ethanol	572	101.7	80.3	51.4
Biodiesel	453	75.9	66.8	57.4

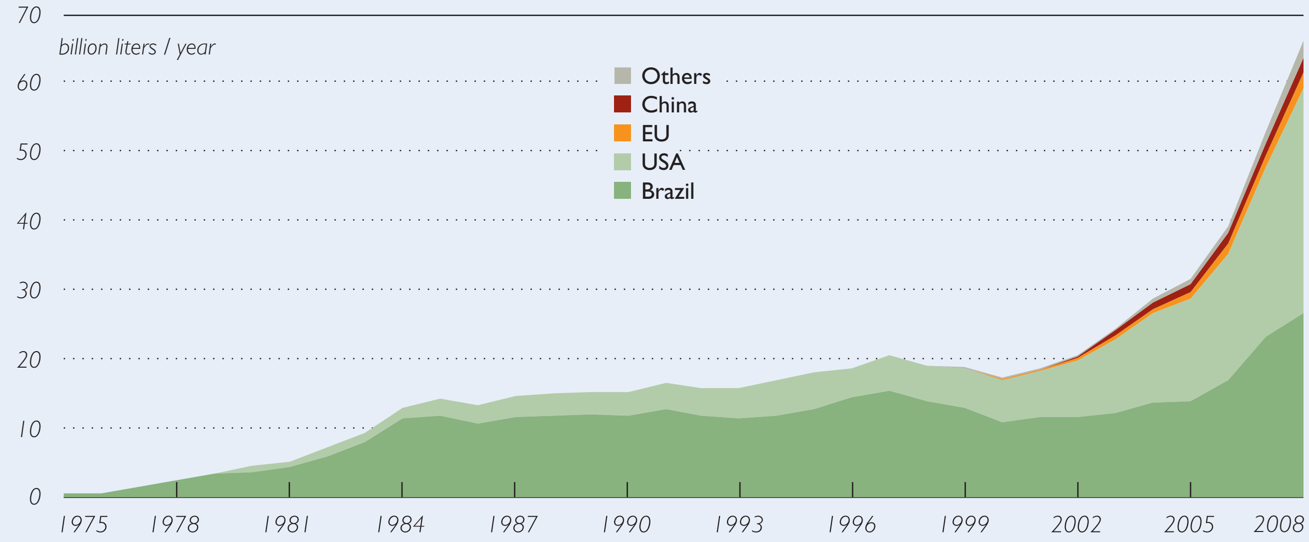
Source: http://www.worldbioplants.com/index.php, accessed 20th January 2008

Biofuel production in 2007 by country Table 2.3 - 2

Mtoe	Bioethanol	Main feedstocks	Biodiesel	Main feedstocks	Total biofuels	Share in total
World	28.57		7.56		36.13	100%
of which						
USA	14.55	Maize	1.25	Soybean	15.8	43.7%
Brazil	10.44	Sugar cane	0.17	Soybean	10.6	29.4%
EU	1.24	Wheat, Maize, Sugar beet	4.52	Rapeseed	5.8	15.9%
China	1.01	Maize, Wheat	0.08	Used oils	1.1	3.0%
Canada	0.55	Wheat	0.07		0.6	1.7%
India	0.22	Sugar cane	0.03		0.3	0.7%
Indonesia	0.00		0.30	Palm oil	0.3	0.8%
Malaysia	0.00		0.24	Palm oil	0.2	0.7%

Source: Production volumes based on F.O. Licht; Mtoe taken from FAO 2008, p.15

World fuel ethanol production Figure 2.3 - 1



Source: F.O. Licht World Ethanol & Biofuels Report, October 2007 and May 2008.

together contribute more than two thirds of global biofuel production amounting to 16 and 11 Mtoe respectively, and account for 87 percent of global bio-ethanol production. Approximately 6 Mtoe of biofuels are produced in the European Union, which is the largest producer and consumer of biodiesel, accounting for 60 percent of global production.

Ethanol

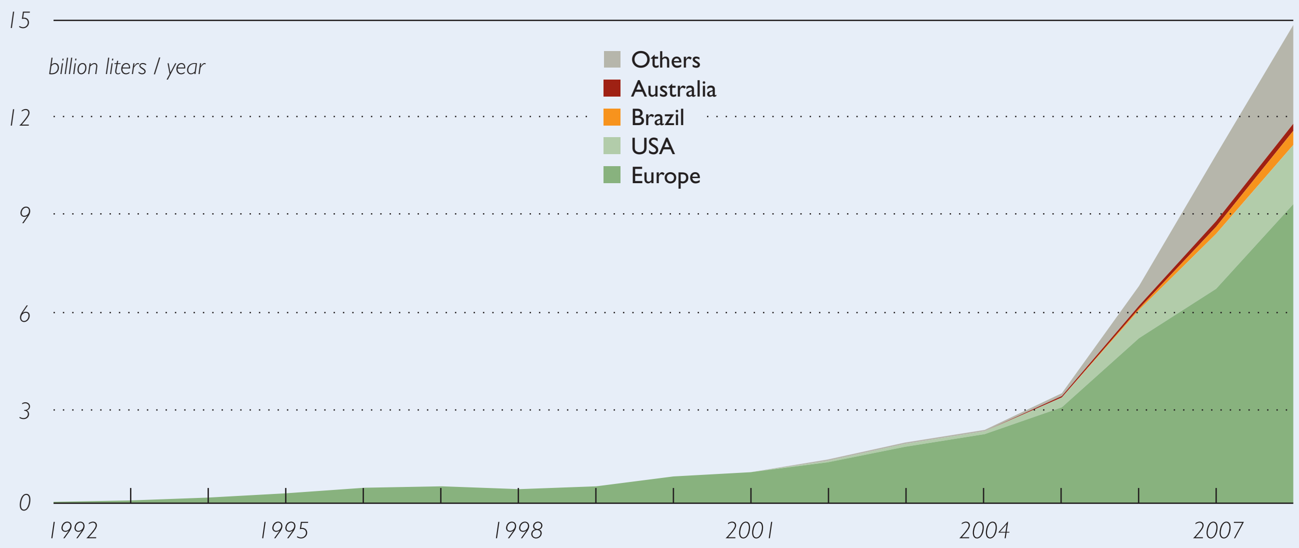
Fuel ethanol production started in Brazil in the late 1970s converting sugar cane to ethanol. By 2005, the USA overtook Brazil as the world's largest bio-ethanol producer and consumer, and by 2008, approximately 50 percent of global ethanol production was located in the USA, with maize being the prime feedstock. About 40 percent was produced in Brazil (Figure 2.3-1) from mainly sugar cane.

In 2007, approximately 277 million tons of sugar feedstocks (sugar cane, sugar beet, and molasses) were used for ethanol worldwide, with Brazil being the most important player (260 million tons of sugar cane and 9.7 million tons of molasses). In addition, approximately 72.5 million tons of grains, mainly maize and wheat, were used to produce ethanol, predominantly in the USA (63 million tons). The remainder comes primarily from wheat-based production in the EU and China. In 2007, ethanol production represented a 4.5 percent share of total worldwide grain production (3.3 percent in 2006). If the by-products sold on the livestock feed markets are taken into account, the net share of grain used for ethanol was approximately 3 percent in 2007.

Biodiesel

Biodiesel production is concentrated in the European Union but other countries are gaining importance (Figure 2.3-2). The EU's biodiesel production took off in the beginning of the 1990s, primarily to support the agricultural sector, which was facing overproduction at that time. Germany and France account for over two thirds of biodiesel production in the EU. Recently, other regions

World biodiesel production Figure 2.3 -2



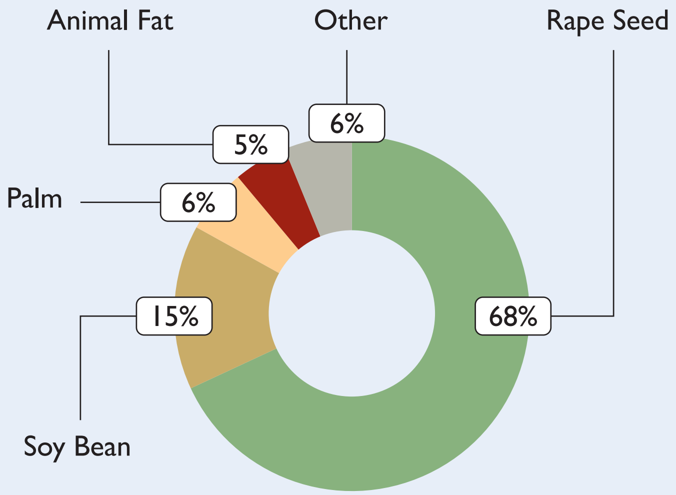
F.O. Licht World Ethanol & Biofuels Report, October 2007 and May 2008.

have started to introduce biodiesel in their markets, notably the USA using soybean as the main feedstock.

Feedstocks for today's biodiesel production are dominated by rapeseed (68 percent) followed by soybean (15 percent). Less important feedstocks include palm oil (6 percent), animal fats (5 percent), various other oils (6 percent), castor seed, and jatropha (Figure 2.3-3).

In 2007, global use of vegetable oils (rapeseed, soybean, oil palm) for biodiesel production totaled approximately 7.8 million tons, of which the EU produces the largest share, i.e., 4.7 million tons (mainly rapeseed oil). In 2007, the EU used approximately 40 percent (35 percent in 2006) of available vegetable oil to produce biodiesel. In 2007, a total of 2.5 million tons of vegetable oil was used in North and South America to make biodiesel, representing 8.4 percent of vegetable oil supply, up from 2.8 percent in 2006.

Raw material sources for today's biodiesel production Figure 2.3 - 3



Source: Mittelbach, IEA39 Workshop Vienna, September 2008.

2.3.2

Ethanol production in the United States of America

The focus in the USA has been mainly on ethanol from maize. The biodiesel share has been growing but at a lower rate. The USA Administration has continuously maintained national tax incentives to encourage ethanol fuel production and use since 1978 (Box 2.3-1).

Bio-ethanol consumption soared in the USA after 2003 as shown in Figure 2.3-4. Today, over 140 ethanol plants are operating with the majority being located in the Mid West corn belt.

The majority of ethanol consumption in the USA is satisfied by domestic production. Only recently have imports increased (ranging between 5 and 10 percent of consumption), in particular from Brazil and Caribbean countries (Tables 2.3-3 and 2.3-4). A tariff on imported ethanol gives domestic ethanol producers a competitive advantage over foreign producers. The USA *ad valorem* tariff is 2.5 percent of the product value, and a secondary duty of US$0.54 per gallon.

The USA Congress has created some unilateral trade preference programs, such as the Caribbean Basin Initiative and the Andean Trade Preference Act that allow ethanol produced in those countries to enter the USA duty free.

Biofuel policies in the United States of America

Box 2.3 - 1

A range of policies are currently being implemented to promote bioenergy, including the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007, the 2002 Farm Bill, and the Biomass Research and Development Act of 2000. Several of these affect liquid biofuels for transport.

The Renewable Fuels Standard (RFS) of the Energy Policy Act of 2005 mandated that total consumption of motor fuels in the USA must include at least 7.5 billion gallons of biofuels.

The 2005 Act also continued funding for the Biomass Program, providing more than US$ 500 million to: promote use of biotechnology and other advanced processes to make biofuels from cellulosic feedstocks cost-competitive with fossil fuels; to increase the production of bio-products that reduce the use of fossil fuels in manufacturing facilities and; to demonstrate the commercial application of integrated bio-refineries that use cellulosic feedstocks to produce liquid transport fuels, high-value chemicals, electricity and heat.

The Energy Independence and Security Act of 2007 established more ambitious quantitative targets, stipulating a volume for 2008 of 9 billion gallons of biofuels and a phased increase to 36 billion gallons (136 million m^3) by 2022. Of the latter, 21 billion gallons (80 million m^3) should be covered by advanced biofuels (with 16 billion from cellulosic biofuels and 5 billion from undifferentiated advanced biofuels).

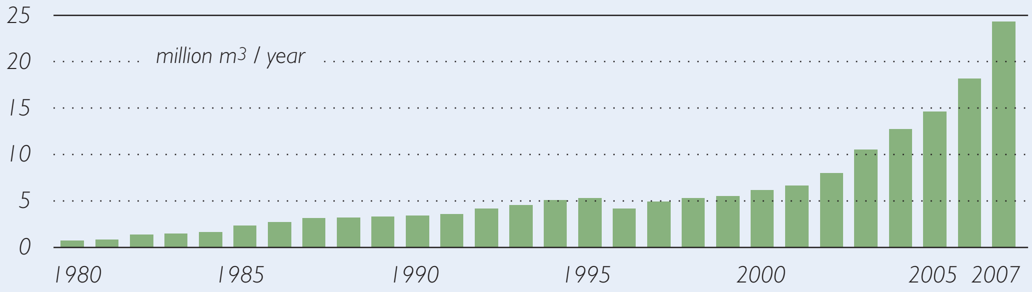
In terms of grants, the 2007 Energy Independence and Security Act authorized US$ 500 million annually for the fiscal years 2008–15 for the production of advanced biofuels with at least an 80 percent reduction of total greenhouse gas emissions relative to fossil fuels. It likewise foresaw a US$ 200 million grant program for the installation of distribution infrastructure for ethanol-85.

The 2007 Farm Bill, approved by Congress in May 2008, reduced the tax credit for maize-based ethanol from 51 to 45 cents per gallon and introduced a tax credit for cellulose-based ethanol.

Source: FAO, 2008a; based on GBEP, 2007, USDA 2008a, and RFA, 2008a.

Evolution of USA fuel ethanol production

Figure 2.3 - 4



Source: [RFA, 2008]

Evolution of USA fuel ethanol market

Table 2.3 - 3

	2002	2003	2004	2005	2006	2007	2008**
Total Ethanol plants	61	68	72	81	95	110	134
million liters							
US Production	8063	10599	12870	14778	18378	24605	32174
Imports	174	231	609	511	2473	1703	
Exports	n/a	n/a	n/a	30	n/a	n/a	
Stocks Change	-344	148	-117	-68	409	0	
Demand	7893	10978	13363	15327	20356	0	

Source: RFA, International Trade Commission, Jim Jordan & Associates; available at: RFA 2008. http://www.ethanolrfa.org/industry/statistics/

** estimate based on January to June production data

USA Fuel ethanol imports by country

Table 2.3 - 4

million liters	2002	2003	2004	2005	2006	2007
Brazil	0	0	342	118	1642	715
Costa Rica	45	56	96	126	136	149
El Salvador	17	26	22	90	146	277
Jamaica	110	149	139	137	253	285
Trinadad & Tobago	0	0	0	38	94	162
Canada	0	0	0	0	0	20
China	0	0	0	0	0	17
Other	2	0	4	0	0	90
Total	172	231	605	511	2473	1613

Source: International Trade Commission – Data downloaded from: RFA 2008. http://www.ethanolrfa.org/industry/statistics/

Biofuel policies in Brazil

Box 2.3 - 2

In 1975, following the first oil crisis, the Brazilian Government launched the National Ethanol Program (ProAlcool), creating the conditions for large-scale development of the sugar and ethanol industry. The program was aimed at reducing energy imports and fostering energy independence. Its main goals were to introduce into the market a mixture of petrol and anhydrous ethanol and to provide incentives for the development of vehicles that were fuelled exclusively with hydrated ethanol. Following the second major oil shock, in 1979, a more ambitious and comprehensive program was implemented, promoting the development of new plantations and a fleet of purely ethanol-fuelled vehicles. A series of tax and financial incentives was introduced. The program induced a strong response, with ethanol production rising rapidly along with the number of vehicles running exclusively on ethanol.

Subsidies provided through the program were intended to be temporary, as high oil prices were expected to make ethanol competitive with petrol in the long run. However, as international oil prices fell in 1986, the elimination of subsidies became problematic. In addition, rising sugar prices led to a scarcity of ethanol and in 1989 severe shortages in some of the main consuming centers undermined the credibility of the program.

The period from 1989 to 2000 was characterized by the dismantling of the set of government economic incentives for the program as part of a broader deregulation that affected Brazil's entire fuel supply system. In 1990, the Sugar and Ethanol Institute, which had regulated the Brazilian sugar and ethanol industry for over six decades, was closed, and the planning and implementation of the industry's production, distribution and sales activities were gradually transferred to the private sector. With the end of the subsidies, the use of hydrated ethanol as fuel diminished drastically. However, the mixture of anhydrous ethanol with petrol was boosted with the introduction in 1993 of a mandated blending requirement specifying that 22 percent of anhydrous ethanol must be added to all petrol distributed at retail petrol stations. The blending requirement is still in place today, with the Inter-Ministerial Board for Sugar and Ethanol establishing the required percentage, which can range from 20 to 25 percent.

The most recent phase of the Brazilian ethanol experience began in 2000 with the revitalization of ethanol fuel, and was marked by the liberalization of prices in the industry in 2002. Ethanol exports increased further as a result of high oil prices in the world market. The dynamics of the sugar and ethanol industry began to depend much more on market mechanisms, particularly in the international markets. The industry has made significant investments, expanding production and modernizing technologies. An important factor in domestic market development in recent years has been the investment of the automobile industry in bi-fuel or dual-fuel alcohol–petrol cars, also referred to as flex-fuel vehicles, which are able to run on a blend of petrol and ethanol.

Biodiesel, by contrast, is still an infant industry in Brazil, and biodiesel policies are much more recent. The biodiesel law of 2005 established minimum blending requirements of 2 percent and 5 percent to be accomplished by 2008 and 2013 respectively. Reflecting social inclusion and regional development concerns, a system of tax incentives was established for the production of raw materials for biodiesel on small family farms in the north and northeast regions of Brazil. Under a special scheme, the "Social Fuel Seal" (*Selo Combustível Social)* program, biodiesel producers who buy feedstocks from small family farms in poor regions pay less federal income tax and can access finance from the Brazilian Development Bank. The farmers are organized into cooperatives and receive training.

Current bioenergy policies in Brazil are guided by the Federal Government's *Agroenergy Policy Guidelines,* prepared by an interministerial team. Linked to the overall policy of the Federal Government, the Ministry of Agriculture, Livestock and Food Supply has prepared a program to meet the bioenergy needs of the country. The goal of the Brazilian Agroenergy Plan 2006–2011 is to ensure the competitiveness of Brazilian agribusiness and support specific public policies, such as social inclusion, regional development and environmental sustainability.

Source: FAO, 2008a; GBEP, 2007, and Buarque de Hollanda and Poole, 2001.

2.3.3

Ethanol production in Brazil

During the last 30 years, Brazil has become the world's major producer of sugar cane and today accounts for approximately one third of global production. This development has been driven primarily by domestic policies (Box 2.3-2) fostering bio-ethanol production to increase energy self-reliance and to reduce the import costs for petroleum.

Today, approximately 45 percent of all energy consumed in Brazil comes from renewable sources; from hydroelectricity (14.5 percent) and biomass (30.1 percent). The country has accumulated significant experience and expertise in the area of biofuels, particularly concerning the use of ethanol as a transport fuel. Brazilian ethanol today is cost competitive with fossil gasoline and replaces a significant portion of domestic road transport fuels[1]. Brazil is the world's largest exporter of ethanol. In 2007, 3.5 billion liters, 20 percent of Brazilian production, were exported, accounting for 50 percent of global ethanol exports.

Figure 2.3-5 shows the dynamics of area expansion for sugar cane cultivation in Brazil and land dedicated to ethanol production since the early 1970s. The figure illustrates three phases that characterize the last three decades. The first decade during 1975 to 1986, showed a sharp increase in Brazilian sugar cane area, which was entirely due to the domestic feedstock demand of the ethanol program. During 1986 to 2000, sugar production grew while ethanol production stagnated, mainly attributed to the low prices of petroleum. Rapid expansion of sugar cane harvested areas occurred after 2000. The demand to substitute ethanol for gasoline became a driving force globally, because of the desire to reduce greenhouse gas emissions and dependence on imported fossil oil.

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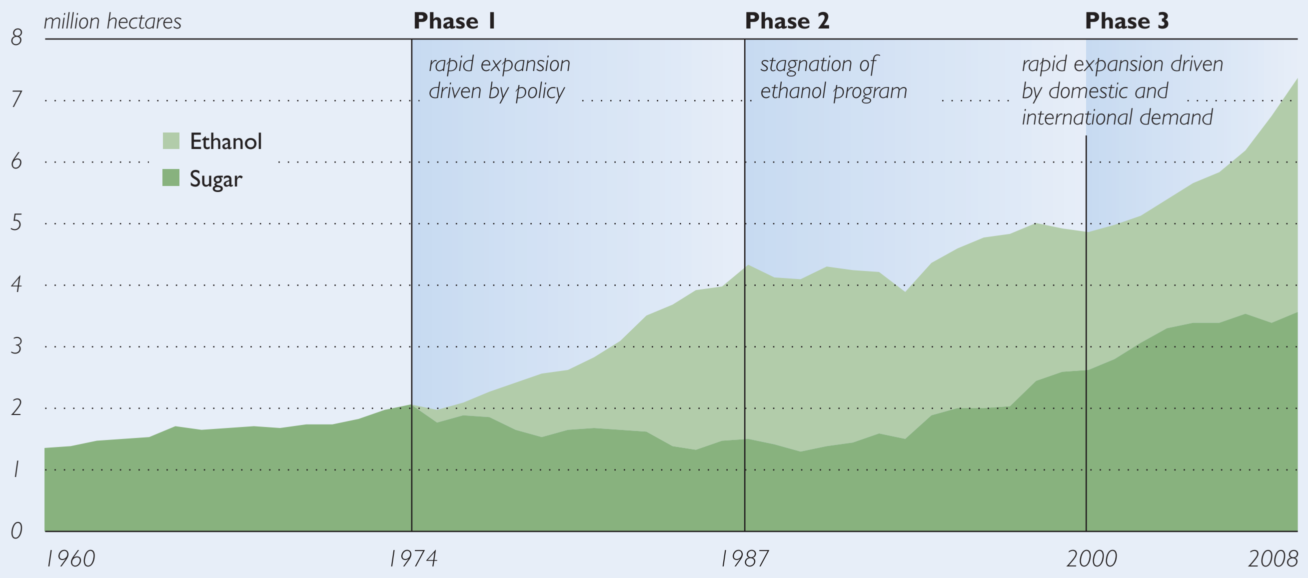
[1] In 2008 more than 50 percent of fuel consumption in the gasoline market was from sugar cane-based ethanol. When trucks and other diesel-powered vehicles are considered, ethanol produced from sugar cane represented 18 percent of the country's total fuel consumption in 2006.

Use of Brazilian sugar cane land for ethanol and sugar production Figure 2.3 - 5



Source: FAOSTAT, 2008; Conab, 2008; F.O. Licht, 2007, 2008; calculation by authors.

2.3.4

Bio-diesel production in the European Union

In the EU, the transport sector produces approximately 20 percent of total anthropogenic greenhouse gas (GHG) emissions. EU governments favor biofuels as they are considered to reduce emissions and offer increased energy security through diversification of fuel sources. Also biofuel production may enhance economic development in rural regions.

Biofuels are supported and regulated on an EU (Box 2.3-3) and Member State level with the instruments being closely interlinked. The Common Agricultural Policy (CAP) regulates support for agricultural production. Otherwise, the EU provides the framework (e.g. allowing for tax exemptions of biofuels) and leaves the decision on concrete policy measures to the Member States. The main policy measures applied in the European Union supporting the introduction of biofuels are summarized in Table 2.3-5.

Over the last few years, the biofuels sector has grown rapidly in the European Union, although only a few countries participate in biofuels production and consumption. In 2007, the European Union consumed 7.7 Mtoe of biofuels, more than half of those in Germany alone (Table 2.3-6). This represented 2.6 percent of the energy content of all the fuels used in EU road transport. Nearly half of the target of 5.75 percent for 2010 set by the directive on biofuels has been reached in just four years (EurObserv'ER, 2008).

Main policy measures for the support of biofuel introduction Table 2.3 - 5

Stage	Measure	Application
Feedstock	Support to agriculture (energy crop subsidy/set aside land)	EU15 → EU27
Production	RD&D funding	EU + country level
	Loans and subsidies for biofuel production facilities	FR, DE, PL, ES, SWE,…
	Producer tax incentives for biofuel production	CZ, LV
	Authorized quota system for biofuel producers, related to tax reduction	FR, IT, BE
Distribution	Standards (biofuel & normal fuel)	AT, DE, FR, SWE, CZ, IT, EU (2003)
	Tax differential (tax reduction for biofuels)	DE, FR, AT, ES, SE, … EU *
	Obligations for fuel distributors	AT, FR, SL, DE, NL, UK,…
	Obligations for filling stations	SWE
	Loans and subsidies for filling stations	DE
Market	Funding of demonstrations	EU + country level
	Procurement methods (green proc., common procurement)	SWE, FR
	User incentives (tax incentives biofuel vehicles, free parking, exemption of congestion charge or other road tax, …)	SWE

Source: [Pelkmans, 2006, 2008] & various country reports

* (Energy Taxation Directive 2003)

Biofuel policies in the European Union

Box 2.3 - 3

EU ***biofuel legislation*** consists of three main Directives. *The first pillar* is Directive 2003/30/EC for promotion of a biofuels market in the EU. To encourage biofuel use, in competition with less costly fossil fuels, the Directive sets a voluntary "reference target" of 2 percent biofuel consumption (on the basis of energy content) by 2005 and 5.75 percent by 31 December 2010. It obliges Member States to set national indicative targets for the share of biofuels, in line with reference percentages of the Directive, although it leaves them free to choose a strategy to achieve these targets.

The second pillar is Directive 2003/96/EC, which allows for the application of tax incentives for biofuels. Taxation not being within the sphere of action of the European Community, each Member State can decide on a level of taxation for fossil fuels and biofuels. However, these tax exemptions are considered as environmental state aid and therefore their implementation by Member States requires authorization from the European Commission in order to avoid undue distortion of competition.

The third pillar of the EU biofuel legislation concerns environmental specifications for fuels indicated in Directive 98/70/EC amended by Directive 2003/17/EC. The Directive contains a 5 percent limit on ethanol blending for environmental reasons. The Commission has proposed an amendment that includes a 10 percent blend for ethanol.

Bioenergy support has also been introduced as part of the ***Common Agricultural Policy***, especially following its reform in 2003. By cutting the link between payments made to farmers and the specific crops they produce, the reform allowed them to take advantage of new market opportunities such as those offered by biofuels. An energy crop premium of 45 Euro per hectare was introduced for a maximum area of 1.5 million hectares, which was later (in 2007) extended to 2 million hectares and included the new EU member countries in Eastern Europe. The aid was available for energy crops grown on non-set-aside land (traditional food crop areas). In addition, while farmers cannot cultivate food crops on set-aside land, non-food crops could be grown on set-aside land, without losing the set-aside premium (around € 300 per ha, depending on average yields[2]). Initially the response for this premium from agriculture was lower than expected[3]. However, by 2007, the maximum area was reached and practically no energy crops were grown without this support.

In its proposals for a "Health Check" of the CAP [EC DG AGRI, 2008[4]], the Commission proposed to abolish the energy crop premium and the compulsory set-aside. In this case no specific support for bioenergy production will be left in the first pillar of the CAP. It is expected that biomass production will continue to grow stimulated by strong demand due to the political targets. In response to the increasingly tight situation on the cereals market [DG IP/08/1069] it was decided in July 2008 that from 2009 onwards compulsory set-aside will be abolished[5].

Support to bioenergy comes also from the new EU ***rural development policy***, which includes measures to support renewable energies, such as grants and capital costs for setting up biomass production.

In January 2008, the European Commission, based on the Commission's Communication *An energy policy for Europe,* has put forward a proposal for a Directive, the ***Renewable Energy Directive*** (RED)[6], to achieve a 20 percent share of renewable energies in overall EU energy consumption by 2020, as well as a 10 percent binding minimum target for the share of biofuels in overall EU petrol and diesel consumption for transport. The latter target is subject to production being sustainable, second-generation biofuels becoming commercially available, and the fuel-quality Directive being amended to allow for adequate levels of blending (Council of the European Union, 2007). The Directive is embedded in the wider 20-20-20 aims, presented in the Energy Policy Package on 23 January 2008. It aims to have by 2020: (i) 20 percent improvement of energy efficiency; (ii) 20 percent reduction of greenhouse gas emissions; and (iii) 20 percent renewable energy. On 13 November 2008, the European Commission proposed a wide-ranging energy package which aims to gives a new boost to energy security in Europe, supporting the 20-20-20 climate change proposals (EC, 2008).

The final agreement on the RED was made on Monday 8 December 2008[7] at the negotiation session between the European Parliament, Council (which is all 27 EU Member States) and the Commission. Instead of the initially proposed target for 10 percent of transport fuel to come from biofuels, the agreement foresees that by 2020 renewable energy - biofuels, electricity, and hydrogen produced from renewable sources - account for at least 10 percent of the EU's total fuel consumption in all forms of transport. 'Second-generation' biofuels produced from waste, residues, or non-food cellulosic and lignocellulosic biomass will be double credited towards the 10 percent target. Renewable electricity consumed by electric cars will be considered 2.5 times its input.

The new legislation established binding criteria to ensure that biofuels production is environmentally sustainable. Biofuels must save at least 35 percent of GHG emissions compared to fossil fuels, which will be increased to 50 percent for existing installations and 60 percent for new installations by 2017. The Commission will develop a methodology to measure the greenhouse gas emissions caused by indirect land use changes - that is when crops for biofuels production are grown in areas which have previously been used to grow a food crop and this food crop production then moves to other areas which were not in use before (e.g. existing forests). In 2014, there will be a review on the progress of renewables, but the compulsory 20 percent renewables targets will not be affected by the review.

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2 However, the amount of oilseed grown for biofuels on set-aside was limited by the Blair House Agreement. It restricts the maximum EU oilseed area for food use to somewhat less than 5 million ha, and the annual output of oil meal from oilseeds planted on set-aside land for industrial use to 1 million tons of soybean meal equivalent.

3 Response was probably low due to the fairly low premium, and the administration needed to receive it.

4 http://ec.europa.eu/agriculture/healthcheck/index_en.htm

5 For autumn 2007 and spring 2008 sowings the rate of set-aside has already been set at 0 percent.

6 Negotiations with Member States and the European Parliament are ongoing, but the Directive is likely to be agreed in early 2009.

7 http://www.europarl.europa.eu/news/expert/infopress_page/051-44023-343-12-50-909-20081209IPR44022-08-12-2008-2008-false/default_en.htm

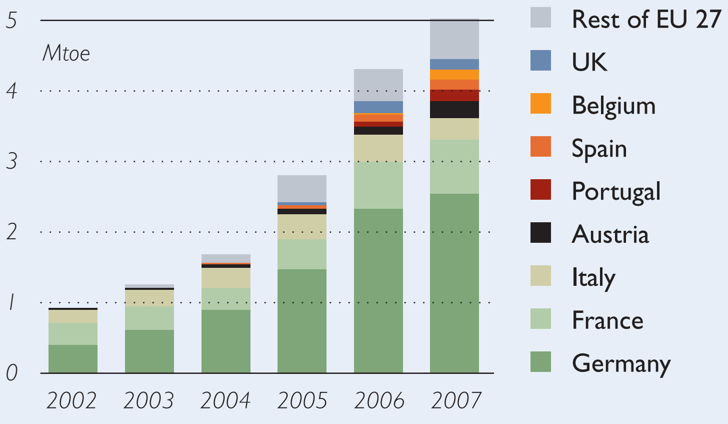
Sources: FAO, 2008a; GBEP, 2007, and information from the Web-site of the European Commission.

The European Union is the biggest producer of biodiesel in the world. The vast majority of biodiesel consumed has been produced domestically. While in 2002 biodiesel was produced only in Germany, France, Italy, and Austria, other countries also have recently invested in production capacity. In 2007, biodiesel production amounted to 5.1 Mtoe (5.7 million tons) with Germany being the major contributor (51 percent) followed by France (15 percent) (Figure 2.3-6).

Biodiesel production today is well below capacity. The European Biodiesel Board reports a total of 214 biodiesel production facilities ready to produce up to 16 million tons of biodiesel (13.8 Mtoe) [EBIO 2008[9]].

The main feedstock used is rapeseed (approximately 80 percent), with sunflower oil and soybean oil making up most of the rest. The EU industry has been slower to invest in ethanol production, which totaled almost 3 billion liters in 2007. The main ethanol feedstocks are sugar beet and wheat cereals. Cultivated land used for biofuel feedstocks has grown steadily and reached 4 million hectares in 2007 (Table 2.3-7). This compares to 115 million hectares of arable land in the EU.

EU biodiesel production 2002 to 2007 Figure 2.3 - 6



Source: European Biodiesel Board - http://www.ebb-eu.org/stats.php

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8 Straight vegetable oil consumed as transport fuel

9 http://www.ebb-eu.org/stats.php and http://www.ebbeu.org/EBBpressreleases/EBB%20Brochure%20FINAL%2025.07.08.pdf

Biofuels consumption for transport in the European Union in 2007 Table 2.3 - 6

Mtoe	Biodiesel	Bioethanol	Other *	Total
EU-27	5774	1166	754	7694
of which:				
Germany	2957	293	752	4003
France	1161	273	0	1434
Austria	367	22	0	389
Spain	261	113	0	373
UK	271	78	0	349
Sweden	100	182	0	281
Portugal	159	0	0	159
Rest of EU27	757	388	1	1146

Note: Pure vegetable oil consumed as transport fuel

Source: Biofuels Barometer 2008

* Straight vegetable oil consumed as transport fuel

EU arable land with energy crops, by type of support Table 2.3 - 7

Million ha	2003	2004	2005	2006	2007
Total non-food land use on set-aside area	0.9	0.5	0.9	1.0	1.0
- oilseeds		0.5	0.7	0.8	0.8
- of which rapeseed		0.4	0.7	0.8	0.8
- cereals		0.0	0.1	0.1	0.1
Total land use on land with crop premium		0.3	0.6	1.3	2.8
- oilseeds		0.2	0.4	0.9	2.0
- of which rapeseed		0.2	0.4	0.8	2.0
- cereals		0.0	0.1	0.2	0.3
Total land use on land without support	0.3	0.8	1.6	1.4	0.2
- oilseeds (rapeseed)		0.8	1.3	0.9	0.1
- cereals			0.3	0.4	0.0
Total	1.2	1.6	3.1	3.7	4.0

Source: [EC DG AGRI, 2008]

Sustainability criteria for biofuels

After decades of overproduction in European agriculture, and subsequent measures to limit surplus production and take farmland out of cultivation, the potential of renewable energy from biomass grown on agricultural land has reversed the focus of debate towards scarcity of agricultural land resources. Recently, soaring agricultural commodity prices have triggered controversial views about the use of arable land for the production of biofuels as opposed to the production of food and feed.

In particular, the 10 percent biofuels target has initiated debates on the viability, potentials, and risks of increased biofuel deployment. Criteria for addressing a wide range of sustainability concerns are under discussion. In the Netherlands the 'Cramer criteria' (Commissie Cramer, 2007) defined a set of principles and criteria for the sustainable production of biomass and the processing of biomass for energy, transport fuels, and chemistry. The principles are divided into five themes:

1. Competition with food, local energy supply, medicine, and construction materials,
2. Biodiversity (no adverse effects on protected areas or valuable ecosystems),
3. Environment (management of waste, erosion, water, and emissions),
4. Prosperity,
5. Social well-being (social, human, and property rights).

From April 2008, UK suppliers of biofuels in the transport sector need to report the sustainability of their production. The Renewable Fuels Agency will organize accreditation and data assessment. In Germany, a Biofuels Sustainability Ordinance was approved at the beginning of 2008. Biofuels will only be credited to the EU-quota obligations and are only eligible for tax reductions if the requirements of the Ordinance are met.

The EU's proposal for a Renewable Energy Directive (RED) is directly related to standards for sustainable biomass. Biofuels should deliver a minimum level of greenhouse gas savings, should not be produced from raw material cultivated on land converted from high-carbon-stock or high-biodiversity uses, and should comply with EU environmental requirements for agriculture where applicable. The EC encourages the diversification of the raw materials used for biofuel production. It provides extra incentives for biofuels made from wastes, residues, grasses, straw, and lignocellulose material.

The European Council in its March 2008 assembly stated that in meeting the ambitious targets for the use of biofuels it is essential to develop sustainability criteria to ensure the commercial availability of second-generation biofuels. A task group from the Council drafted a set of sustainability criteria, which are intended for use in both the RED and the Fuels Quality Directive, under revision in parallel (European Commission, 2008).

2.3.5

Biofuel developments in China and India

Biofuel strategies often build on the comparative advantages of agricultural sectors. Considering their size and potential, the emergence of China and India makes their strategies and biofuel implementation plans significant for developments in both global energy and agricultural markets.

China

China's primary energy needs will expand from 1742 Mtoe in 2005 to 3819 in 2030 and will account for almost 30 percent of the increase in global fossil oil consumption over this period. Vigorous growth of transport demand – from a relatively small base – has raised its share from 5 percent of total energy use in 1980 to 11 percent in 2005. Saving energy and expanding domestic supplies are given priority in the 11th Five-Year Plan for Energy, covering the period 2006–2010 (IEA, 2007).

The Chinese government is promoting biofuels, which are seen as part of the answer to China's energy security, rural-development and pollution problems. China initiated its first fuel ethanol production program at the beginning of this decade. After increases in grain prices in 2007 and 2008, the Chinese government became concerned that promotion of biofuels, particularly ethanol, may contribute to food price increases affecting China's food security. This resulted in shifting away from the use of grains as feedstock for biofuels towards promoting feedstocks grown on marginal land, such as cassava, sweet sorghum, and sweet potatoes.

China produces approximately 1.6 million tons of fuel ethanol, with maize as the main feedstock (approximately 80 percent). The biofuel sector is heavily regulated, with new ethanol plants requiring central government approval. China's Medium and Long-Term Development Plan for Renewable Energy designates biomass energy as a priority sector and sets production targets of two million tons of 'non-cereal' ethanol by 2010 and 10 million tons by 2020. China has sufficient marginal cultivated land for growing feedstocks to meet these production targets.

As China is a net importer of vegetable oils, the government does not promote biodiesel. Biodiesel is not distributed through petrol stations in China, nor is there a national biodiesel standard. China's biodiesel industry is dominated by small-scale operators using animal fats or waste cooking oil as feedstock and selling biodiesel directly to users.

Chinese biodiesel production in 2006 was approximately 190,000 tons. Press and other reports indicate that the figure has increased to between 200,000 to 300,000 tons (GSI, 2008). A target for biodiesel use has been set for 200,000 tons by 2010 and 2 million tons by 2020.

India

India's rapid economic expansion will increase primary energy demand. It is expected to double by 2030, with transport energy demand showing the fastest rate of growth (WEO, 2007). Half of India's oil demand comes from the transportation sector and the country currently imports around 75 percent of its oil consumption.

India has an important sugar cane industry based on 4 million hectares of irrigated cultivated land. Part of this production is used for ethanol (1.2–1.8 million tons per year). Support for fuel ethanol production started in 2003, when India's government mandated that nine states and four Union territories were required to sell E-5, a five percent blend of ethanol in gasoline. However, in view of supply constraints from the sugar industry, the original proposal was downsized to only

4 States and later fully suspended. The recovery in sugar and molasses output during 2005–06 generated renewed interest in the ethanol program. In October 2008 the government introduced an E-10 mandate (F.O.Licht 2008).

India's commercial production of biodiesel is almost non-existent. Due to high vegetable oil prices in the domestic market, it is not economically feasible to produce biodiesel. The strategy for biodiesel is based on non-edible oils (mainly jatropha), which would not compete with food use. Today, only small quantities of jatropha and other non-edible oilseeds are crushed for oil, mainly used for lighting. There are ambitious jatropha planting programs but progress so far has been slow. In 2007, India's jatropha plantation area is estimated at around 400,000 hectares, of which the majority comprises new plantations that are not yet productive (Singh, 2007). To supply the transport sector with a 5 percent biodiesel share by 2015, as projected in the IEA Alternative Policy Scenario, 1.2 to 1.4 million hectares of jatropha plantation would be required (IEA, 2007).

The latest National Biofuel Policy (2008) sets a 20 percent target by 2017 for the blending of biofuels. The policies include provisions that discourage the import of biofuels and stimulate the establishment of plantations as a way to boost employment opportunities amongst the rural poor.

2.4. Biofuels technologies

2.4.1

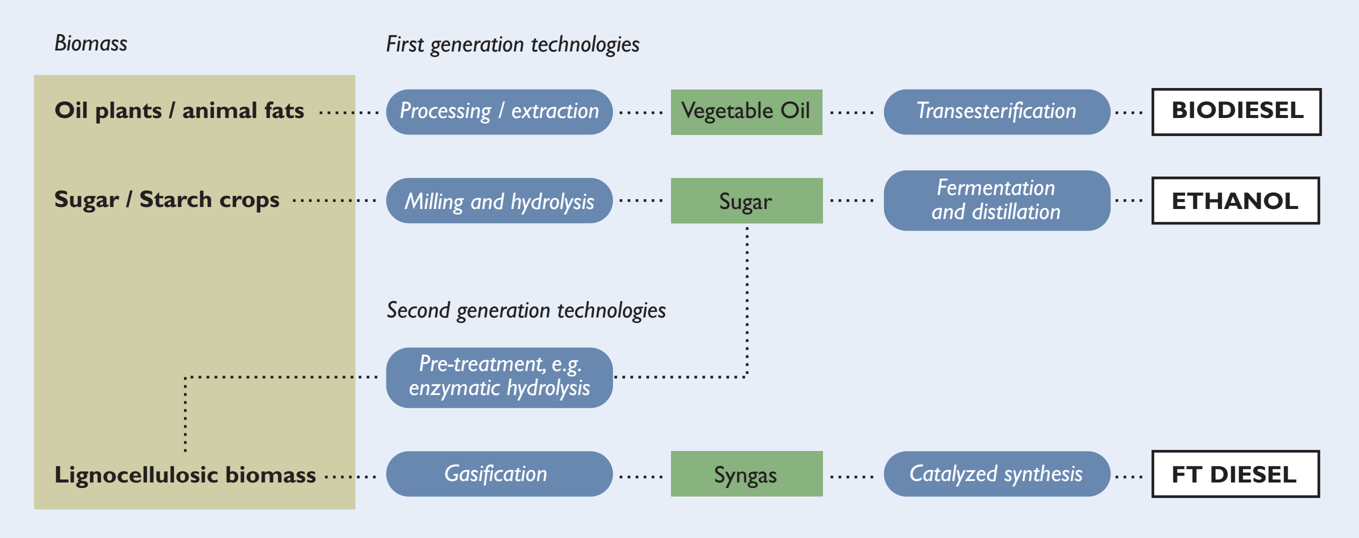
Biofuel production pathways

Current biofuel production processes follow the well-established so-called ***first generation*** conversion pathways relying on sugar, starch, or vegetable oil components of crops (Figure 2.4-1). These are extensively employed in Brazil (sugar cane for bio-ethanol), the United States of America (cereals, mainly maize for bio-ethanol) and the European Union (oilseeds, mainly rapeseed for biodiesel).

Feedstocks utilized for these first-generation technologies are primarily food and feed plants, which have been optimized for nutrition and not for energy output. Hence, most first-generation feedstocks use for biofuels, with the exception of sugar cane, have rather low land use efficiency, i.e. a high land requirement per unit of transport fuel produced.

First-generation biofuel production processes generate both the fuel and various by-products. The type and quantity of by-products depends on the respective biofuel production chain. By-products include valuable livestock feed (e.g. rapeseed cake, soybean meal, or DDGS[10]), biomass fuels (straw, husks and bagasse), and industrial use materials (glycerin). The economic viability of biofuel production depends largely on the ability of the industry to derive value not only from the biofuel it produces, but also from the by-products that are generated during the process. If by-products are effectively utilized then the energy and environmental performance of biofuel production chains can improve significantly. By-product credits include greenhouse gas emission savings, avoided land use, or avoided energy use. Brazilian sugar cane ethanol utilizes wastes and by-products from the milling process to generate heat and electricity. This permits the industry to operate

Transport biofuel production pathways Figure 2.4 - 1



Source: Adapted from Hamelinck and Faaij (2006).

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[10] Distillers' Dried Grains with Solubles (DDGS) are co-products of the fuel ethanol industry. Its use as animal feed depends on the feedstock.

without significant fossil fuel inputs; achieving a high overall greenhouse gas saving of 80–90 percent in comparison to fossil fuel.

The majority of studies on potential biofuel deployment conclude that more extensive use of biofuels will require both an expansion of the range of feedstocks, and the introduction of advanced conversion technologies. Research is underway to develop ***second-generation biofuels*** based on lignocellulosic biomass comprising cellulose, hemicellulose, and lignin. Lignocellulose exists in agriculture and forestry residues (straw, maize stover, and wood) and dedicated energy crops (miscanthus, switchgrass, willow, poplar). Cellulose, a polysaccharide, is the major component of cell walls of plants and contains large reservoirs of energy.

The major bottlenecks currently impeding the practical production of biofuels from cellulosic feedstocks include:

(i) Conversion technology: it is difficult to convert cellulose via enzymatic hydrolysis to sugar for industrial-scale plants at competitive prices; for gasification, as the Fischer-Tropsch synthesis requires a very clean syngas, the gas cleaning remains one of the big challenges for the commercialization of F-T biodiesel.

(ii) Feedstock-supply logistics: industrial-scale conversion plants will require a steady and huge feedstock supply of bulky biomass with associated challenges for pre-treatment to reduce bulk and logistical and transport costs.

2.4.2
Ethanol

The fundamental process in conventional ethanol production technology is the fermentation of sugar. Following a biochemical pathway, involving enzymatic and fermentative processes, yeasts or bacteria feed on sugar in the absence of oxygen producing ethanol and carbon dioxide as metabolic waste products. Ethanol (alcohol) is subsequently extracted as a pure compound through distillation.

Ethanol production is an established technology, although various changes have been introduced in recent decades leading to substantial improvements in production efficiency.

Sugar can be obtained either directly from sugar cane, sugar beet, or sweet sorghum, or derived from the conversion of starch contained in starchy plants, such as cereal grains (e.g. wheat, maize, and barley), millets, and roots and tuber crops (e.g. potato, cassava). While the basic processes for production of ethanol from sugar crops and starchy plants are similar, there are clear advantages in producing ethanol directly from sugar crops because of the additional process required to convert starches into sugar prior to fermentation. The conversion of complex polysaccharides (starch) in the biomass feedstock to simple sugars is a high-temperature process using acids and enzymes as catalyst. Because of this additional step, energy and greenhouse gas balances are mostly more favorable for producing ethanol directly from sugar crops as compared to starchy plants. The energy requirement for converting sugar directly from sugar cane into ethanol is about half that of using maize.

Ethanol is produced in two forms, hydrous and anhydrous. Hydrous ethanol contains water and has a purity of 95 percent, whereas anhydrous ethanol contains no water and is referred to as pure ethanol. Anhydrous ethanol is produced by further dehydrating hydrous ethanol to remove all water content. Hydrous ethanol is currently only used in Brazil as a motor fuel in vehicles with modified engines.

In Brazil, 40 percent of fuel ethanol production is used by vehicles operating on 100 percent ethanol (E100), with the remainder used as a blended fuel, mainly E22. Anhydrous ethanol is used in parts of Europe, the USA, and Australia. It is blended in concentrations of up to ten percent with petrol for use in conventional petrol vehicles and in blends of up to 85 percent for use in vehicles with modified engines known as flexible fuel vehicles (FFVs). Today some 15 million ethanol FFVs are on the roads globally, primarily concentrated in the USA (approximately 8 million or 2.8 percent of the USA vehicle fleet) and Brazil (7 million or 25 percent of the vehicle fleet) (Faaij *et al*, 2008).

Ethanol from sugar cane

The modern cane-based sugar industry has evolved into a complex agro-industrial activity, with the majority of mills designed to produce sugar and ethanol simultaneously[11]. The advantage is greater economic flexibility in response to market conditions. Because of the relatively long history of the cane-based sugar and ethanol industry a variety of by-products have emerged and found markets. There are three types of product streams: sugar/solids, molasses/juice, and crop residues.

The key crop residue is bagasse, fiber left over after the sugar-rich juice has been squeezed out of the stalks. It is used as a primary fuel source for sugar mills enabling them to be more than self-sufficient in energy and allows sugar cane-based ethanol to achieve energy balances that are from two to eight times more efficient than those of fossil fuels. Often co-generation of heat and electricity is possible and surplus electricity can be sold on to the consumer electricity grid thus offering an additional source of income. Surplus bagasse can be used for livestock feed, as well as for the paper industry, or for making insulated disposable food containers.

The production cost of Brazilian sugar cane alcohol remains very competitive despite crude oil prices plunging by more than 50 percent since July 2008[12]. The sunny, warm climate provides conditions for relatively high feedstock yields per hectare. Labor costs are low and efficient co-generation facilities offer additional income from electricity production. Brazil's export of ethanol is reported to remain competitive with oil prices of US$50 per barrel, at current exchange rates. Brazilian ethanol production in 2008–09 is estimated at 26 billion liters, of which about 20 billion liters will be consumed domestically.

Ethanol from sugar beet

Beet processing facilities convert raw sugar beets directly into refined sugar in a one step process. Sugar beets are very bulky and relatively expensive to transport and must be processed fairly quickly before the sucrose deteriorates. Therefore, all sugar beet processing plants are located in the production areas. This limited storage ability is a major drawback of sugar beet use for ethanol production.

Despite the simple processing technique, the cost of ethanol production from sugar beet is approximately twice that of sugar cane-based ethanol in Brazil, or maize-based ethanol in the USA (USDA 2006[13]). This is primarily due to differences in feedstock costs.

Ethanol from starch crops (maize, cassava, and other cereals)

Feedstock grains are cleaned and milled to obtain starchy feedstock. Two forms of milling, wet or dry, can be employed in this process. Wet milling involves soaking feedstock grain to break it down prior to converting the starch to sugar. Dry milling does not utilize this process prior to starch conversion. In both cases, starch is converted to sugar using a high-temperature enzyme process. The sugar is then fermented to ethanol employing the process used for sugar crops described above.

While ethanol fermentation consumes the grain's starch, the protein, minerals, vitamins, fat and fiber can be concentrated during the production process to produce highly

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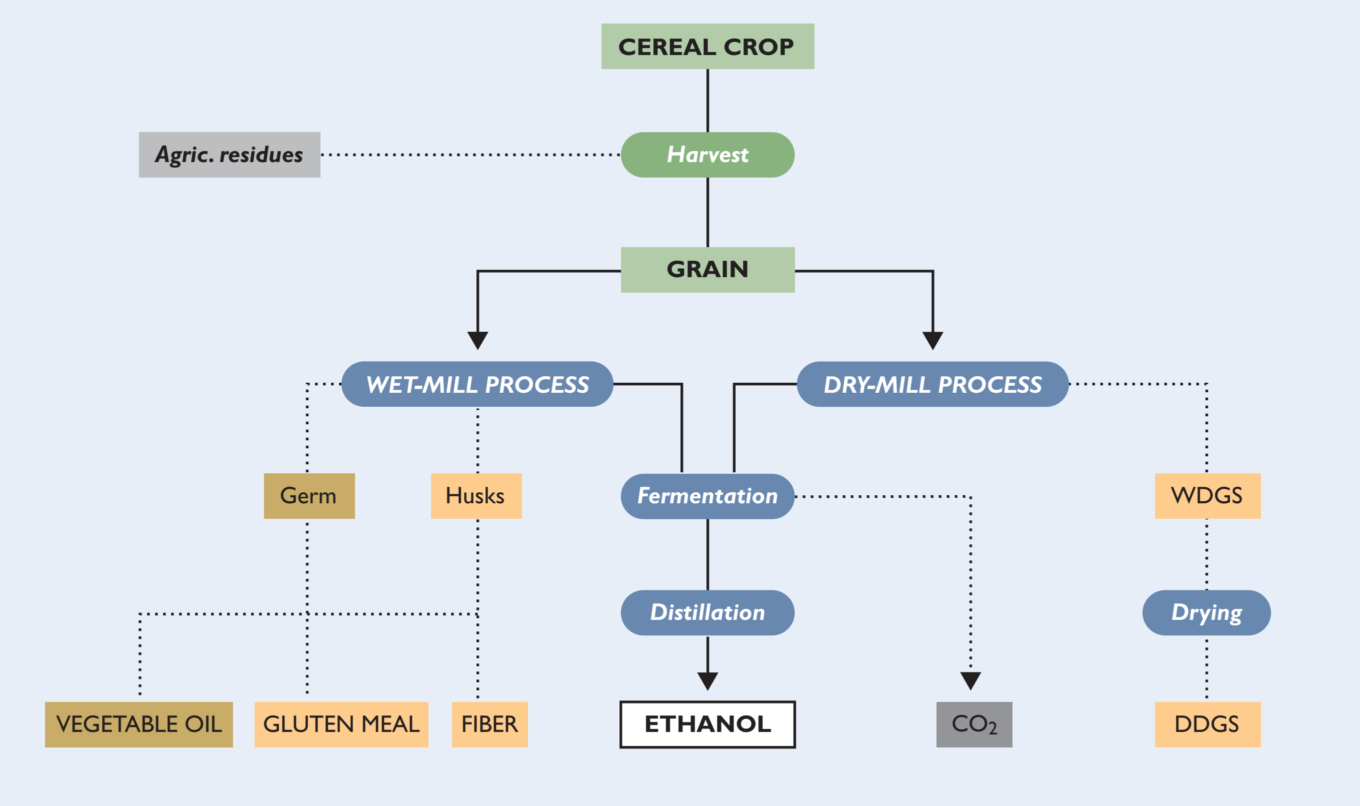
[11] In Brazil there are currently 378 ethanol plants operating, 126 dedicated to ethanol production and 252 producing both sugar and ethanol. An additional 15 plants are dedicated exclusively to sugar production.

[12] http://www.cattlenetwork.com/Content.asp?ContentID=267881

[13] The Economic Feasibility of Ethanol Production from Sugar in the United States, http://www.usda.gov/oce/reports/energy/EthanolSugarFeasibilityReport3.pdf

Process flow and by-products of ethanol production from starch crops Figure 2.4 - 2



valued and nutritious livestock feed and distillers' grains, the principle by-product of ethanol production. The sale of these by-products can generate additional revenue for ethanol manufacturers, and in many cases, this revenue is a critical component of a plant's economic viability. Figure 2.4-2 presents an overview of grain-based ethanol production including by-products generated during the different processing steps.

Distillers' grain is produced from the distillation and dehydration process during ethanol production and provides a high protein livestock feed supplement. Wet Distillers' Grain with Solubles (WDGS) comprises up to 70 percent moisture and has only a short shelf life of between two and five days. As it involves the transport of 70 percent water by weight of the total product, it can only be utilized by feedlots in close proximity to ethanol plants. The alternative to WDGS is to dry the product to produce Dry Distillers' Grain with Solubles (DDGS). While this is an energy-intensive process, DDGS has an almost indefinite shelf life and is relatively easy to transport.

Although wet-mill facilities were common in the industry's early stage, dry-mill facilities now account for the majority of industry capacity. A wet mill facility is considered more versatile compared to a dry mill ethanol plant because it yields more by-products. The starch is extracted for food or industrial uses including ethanol production. The maize oil from the germ is either extracted on-site or sold to crushers who extract the maize oil. The gluten component (protein) is filtered and dried to produce gluten meal, which is highly valuable as a feed ingredient. The fiber derived from the husks or maize oil processing is another valuable feed product.

Dry-mill ethanol plants are optimized to produce ethanol with carbon dioxide and livestock feed as by-products. A wide variety of ethanol by-products is available as livestock feed, but they vary in nutrient content, quality.

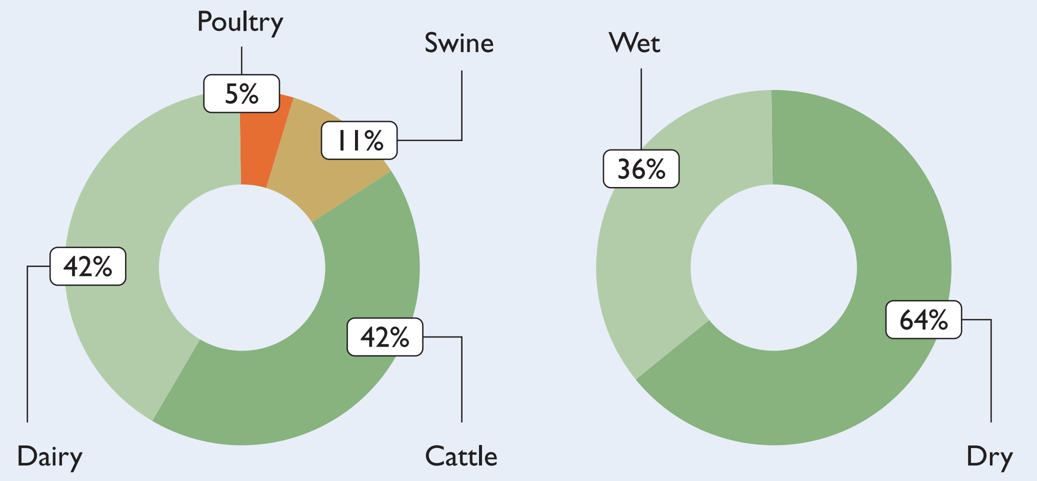
In the USA, approximately 40 percent of the distillers' grains with solubles are marketed as wet by-products (WDGS) for use in dairy operations and beef cattle feedlots. The remaining 60 percent is DDGS and marketed domestically and internationally for use in dairy, beef, swine, and poultry feeds (Figure 2.4-3). In a dry-mill ethanol plant a ton of maize produces 400 liters of ethanol, 315 kilograms of DDGS and 305 kilograms of carbon dioxide[14]. Production and consumption of distillers' grains has risen rapidly with increased ethanol production. In 2007, USA ethanol bio-refineries produced approximately 14.6 million tons of distillers' grains, up from 2.7 million tons in 2000. In 2006, some 800,000 tons of DDGS were exported to the European Union.

Another by-product is carbon dioxide, which is produced during the fermentation process. Many ethanol plants collect the carbon dioxide for use in carbonate beverages or in flash freezing of meat.

Second-generation lignocelluloses

Conventional processes for the production of ethanol rely on feedstocks commonly used as foods, such as grains and sugars. As with food production, a large part of the feedstock plants – such as leaves, stalks, and straw – are not actually used in production and become waste products. These woody or herbaceous waste products, generally referred to as lignocellulosic biomasses, represent a large quantity of potential energy that is not currently utilized. In addition, dedicated lignocellulosic energy feedstocks hold promise as a source of feedstock for second-generation technologies. Potential feedstocks include short-rotation tree species such as willow, poplars, and eucalypt, or perennial grasses such as miscanthus, switchgrass, and reed canary grass. These feedstocks present major advantages over first-generation feedstocks in terms of environmental

North American distillers' grains consumption in 2007 Figure 2.4 - 3



Source: http://www.ethanolrfa.org/industry/resources/coproducts/

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[14] US dry-mill ethanol industry, 2008 http://www.brdisolutions.com/pdfs/drymill_ethanol_industry.pdf

sustainability as, compared with conventional starch and oilseed feedstocks, they can produce more biomass per hectare of land because the entire plant is available as feedstock for conversion to fuel (FAO, 2008a).

Lignocellulose comprises carbohydrate polymers that include cellulose and hemicellulose, lignin, and a remaining small component containing extractives, acids, salts, and minerals. However, cellulose is more resistant to being broken down than starch, sugar, and oils. The difficulty of converting it into liquid fuels makes the technology more expensive, although the cost of the cellulosic feedstock itself is lower than for current first-generation feedstocks.

Interest in the production of renewable energy sources from lignocellulosic biomass is growing substantially with research projects underway in the USA and several other countries. Lignocellulosic technology seeks to break down the cellulose portions of plant matter, through hydrolysis fermentation, into sugars, which are then fermented and distilled to obtain ethanol.

There are two common forms of hydrolysis fermentation. The first is acid hydrolysis that comprises a two-step process of a diluted acid and a concentrated acid. While this technology is the most widely used, it produces a number of undesirable by-products. The second form of hydrolysis utilizes biological enzymes. This technology is still being researched, however, the process is more environmentally sustainable, and delivers high sugar yields of 75–85 percent. In comparison, acid hydrolysis produces sugar yields of 50–70 percent.

Another critical issue refers to the low bulk density of biomass, which requires large volumes of water to be added to create a slurry that can be processed through conventional reactors, pipes, or pumps. Typically, slurries become too viscous and restrict sugar, and subsequent ethanol concentrations. Due to these lower concentrations, biomass-ethanol plants require substantially larger capacities, consume more energy for distillation and produces higher volumes of waste water to be treated (Hamelinck *et al.*, 2005).

While large scale production of ethanol from lignocellulosic biomasses is not yet commercially viable, the technology may provide an avenue to increase ethanol production. Support for this technology is based on the premise that producing biofuels from woody and herbaceous plants will reduce the pressure on the food chain. Second-generation biofuels are expected to offer advantages in terms of reducing greenhouse gas emissions. Life-cycle analyses of advanced fuels from perennial crops and woody and agricultural residues predict dramatically reduced greenhouse gas emissions relative to fossil fuels and first-generation biofuels.

2.4.3
Biodiesel

Biodiesel is a renewable fuel that is currently manufactured from vegetable oils (such as rapeseed, sunflower seed, soybean), and other vegetable oils and fats. Biodiesel has similar qualities to petroleum diesel and is used in blends with petroleum diesel or in its pure form. B20 (20 percent biodiesel and 80 percent petroleum diesel) and lower-level blends such as B2 (2 percent biodiesel and 98 percent petroleum diesel) and B5 (5 percent biodiesel and 95 percent petroleum diesel) can be used in any diesel engine. B100 (pure biodiesel) or other high-level biodiesel blends can be used in special motorized engines built since 1994.

The cost of biodiesel is principally dependent on the price and availability of feedstocks, with prices for principal feedstocks fluctuating sharply in recent years.

Biodiesel from vegetable oils and fats

Vegetable oils are produced by pressing the oil from the seeds and refining it to remove free fatty acids and other impurities. Processing of the seeds for oil production provides protein meal and cake as by-products. Per ton of rapeseed about 0.4 tons of vegetable oil and 0.6 tons of rapeseed cake is produced, which is excellent for livestock feed.

The principal by-product of biodiesel production is glycerol, also known as glycerin. During the transesterification process, 100 kg of glycerin is produced for every 1 ton of biodiesel. This bio-glycerin can substitute conventional fossil glycerin, serving manifold uses in the food and beverages industry, in medical and pharmaceutical applications, and is used to produce nitroglycerine.

As biodiesel production soars, so does the supply of crude natural glycerin. This has resulted in excess glycerin production. Biodiesel refiners operate on narrow profit margins and often sell glycerin to subsidize production. The challenge is to find value-added alternatives and improve environmental benefits and economic viability of the biodiesel supply chain. It is possible to produce useful quantities of biodiesel in relatively small-scale plants, thus offering an advantage for rural economies, particularly in developing countries.

Synthetic Fischer-Tropsch biodiesel (second-generation technologies)

The Fischer-Tropsch (F-T) biodiesel[15] is one of the more advanced options for the production of synthetic biofuels. Synthetic biofuels are fuels that are synthesized from 'Syngas', i.e. synthetic gas produced by thermal gasification of biomass. The F-T process (developed by Franz Fischer and Hans Tropsch), has been known since the 1920s in Germany, but in the past it was mainly used for the production of liquid fuels from coal or natural gas.

The F-T process utilizing biomass as a feedstock is still under development. Choren Industries[16] in Freiburg, Germany have produced synthetic F-T biodiesel under pilot plant conditions, showing that the process is technologically feasible. A key advantage of the gasification pathway is its ability to convert all the components of the biomass feedstock, including the lignin component that cannot be broken down by enzymes in the conventional biochemical conversion process. Hence, the combination of gasification and F-T synthesis can produce more biofuel per ton of biomass than other conversion routes, especially for woody biomass feedstocks.

Fischer-Tropsch diesel is similar to fossil diesel in terms of its energy content, density and viscosity. It can thus be blended with fossil diesel in any proportion without the need for engine or infrastructure modifications. Fischer-Tropsch diesel has a higher cetane number (better auto-ignition qualities) and lower aromatic content, which results in lower Nitrogen oxides (NOx) and particle emissions.

The main technological hurdle to overcome is the production of clean syngas required by the Fischer-Tropsch process. Current biomass pre-treatments and feeding methods require modification because milling the biomass to the small particle size required for gasification is too energy-intensive, and small biomass particles can aggregate and clog feeding lines. In this context, a key research target is the production of catalysts that are more tolerant to impurities.

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[15] F-T biodiesel is also often denoted as "Biomass to Liquid" (BTL) transport fuel.

[16] http://www.choren.com/en/

2.5. **Biofuels and sustainable development issues**

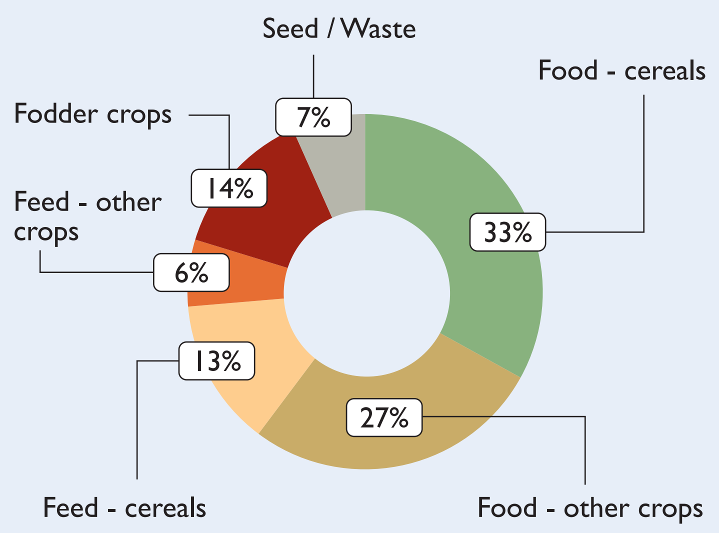
The environmental benefits of increased biofuel deployment and their contribution to sustainable development are at the core of intense debates on the advantages of using biofuels (Scharlemann and Laurance, 2008; Robertson *et al*, 2008). Biofuel sustainability has environmental, economic, and social facets that all interconnect.

Sustainable biofuel production and use should include the following elements:

- significant greenhouse gas savings compared to the use of fossil fuels;
- the use of environmentally sound agricultural and forestry management systems for biofuel feedstock production;
- preservation of landscapes with significant value for biodiversity, nature conservation, and cultural heritage;
- regard for the possibility of social exclusion; and
- integration with food, feed, and other biomass use sectors considering economic, security, and environmental implications of supply and demand patterns.

Closely related to these sustainability requirements is the land use efficiency of biofuel feedstock production and food security. Higher energy yields per hectare reduce land requirements and may decrease land competition with food and feed production.

Global use of arable land for food and feed (2000-02) Figure 2.5 - 1



Source: Calculations by authors based on FAOSTAT.

2.5.1
Competition for cultivated land

A major concern regarding ongoing deployment of the bio-energy sector is the potential impact on food production and food security with respect to competing demands for productive land. Land demand for food, feed, as well as energy crops, will require an increase in agricultural productivity and some expansion of land areas, with mounting pressures to convert forests and areas of high nature conservation values. Soaring agricultural commodity prices, especially in 2007–08, have triggered controversy about the use of arable land for the production of biofuels.

The vast majority of human food intake relies on crops and livestock products from agricultural land, which comprises cultivated land and permanent grassland. Livestock products produced from ruminant livestock account for the majority of livestock commodities. Intensification of the livestock sector and changes in human dietary preferences towards monogastric products have shifted the livestock sectors' feed demand towards an increasing share of feed produced on cultivated land.

Global cultivated[17] land amounts to approximately 1.6 billion hectares and is concentrated in the most productive areas i.e., areas with adequate climatic conditions, fertile soils, and large flat terrains. Based on data on agricultural production, trade, supply, and utilization, from the FAO Statistical database (FAOSTAT), we have estimated the extent of cultivated land that is associated with crop production for human 'vegetarian' consumption and the production of livestock feed. In addition, land that is associated with traded agricultural products was estimated and included in the accounts.

Figure 2.5-1 highlights the distribution of cultivated land used for food production[18] and feed. Approximately 60 percent of global cultivated land is used to produce crops for food, half of which are cereals (mainly rice, wheat, and maize) and half are 'other crops', comprising all non-cereals including root crops, sugar crops, oil crops, and fruit and vegetables. One-third of global cultivated land is used for the production of feed consisting of cereals (mainly maize, wheat, barley, and sorghum), and fodder crops. The remainder (about 7 percent) is associated with 'seed and waste'[19].

Consumption patterns differ significantly between developed and developing countries. In developed countries (Figure 2.5-2a) approximately 30 percent of cultivated land is used for crops and crop products and 54 percent for the production of livestock.

In developing countries (Figure 2.5-2b), 75 percent of cultivated land is used for crop products and approximately 20 percent for livestock. The remaining 'seed and waste' category accounts for approximately 6 percent of cultivated land in both developed and developing countries.

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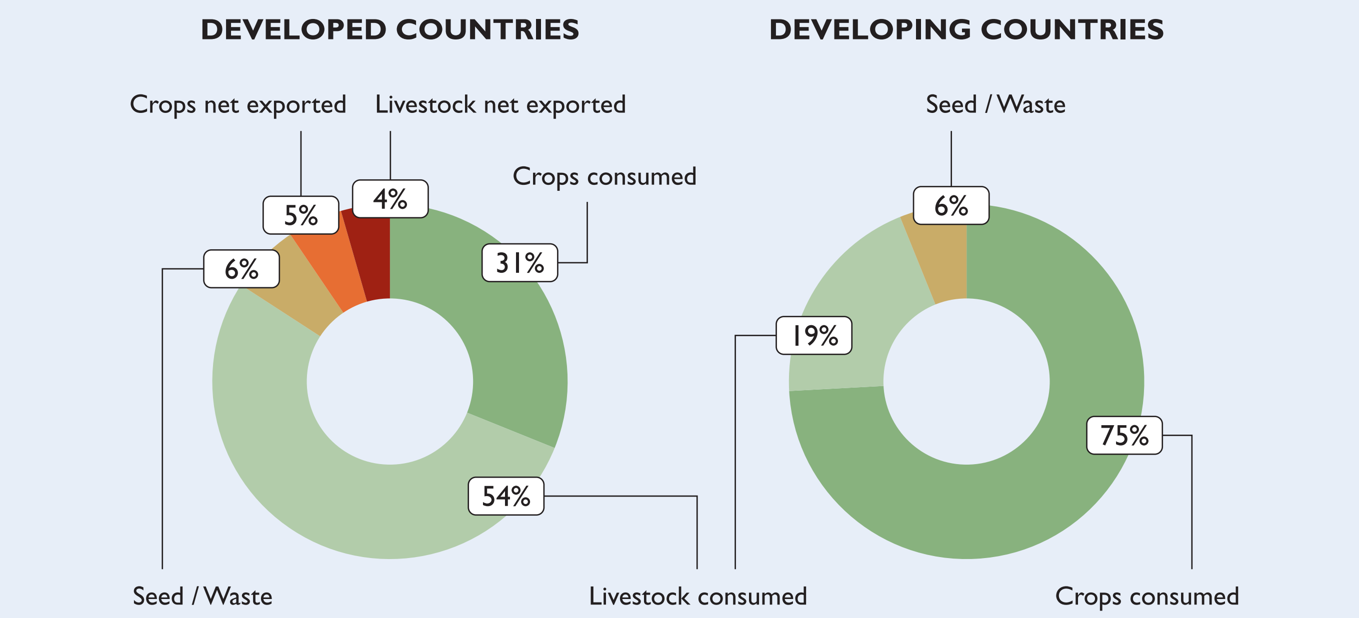
[17] Cultivated land in this study includes permanent crops, accounting for about 10 percent of the total. Permanent crops include vineyards, orchards and plantations of e.g., oil palm, coconut, cacao, coffee and tea. FAOSTAT reports for 2000-02, 1408 million hectares of land under annual crops and 136 million hectares under permanent crops.

[18] Agricultural commodities for direct human consumption include fibers and other industrial crops.

[19] Seed: Data include the amounts of the commodity set aside for nurseries and seed production. Waste: reflects commodity losses through wastage at all stages between farm gate and consumption (including handling, storage and transport).

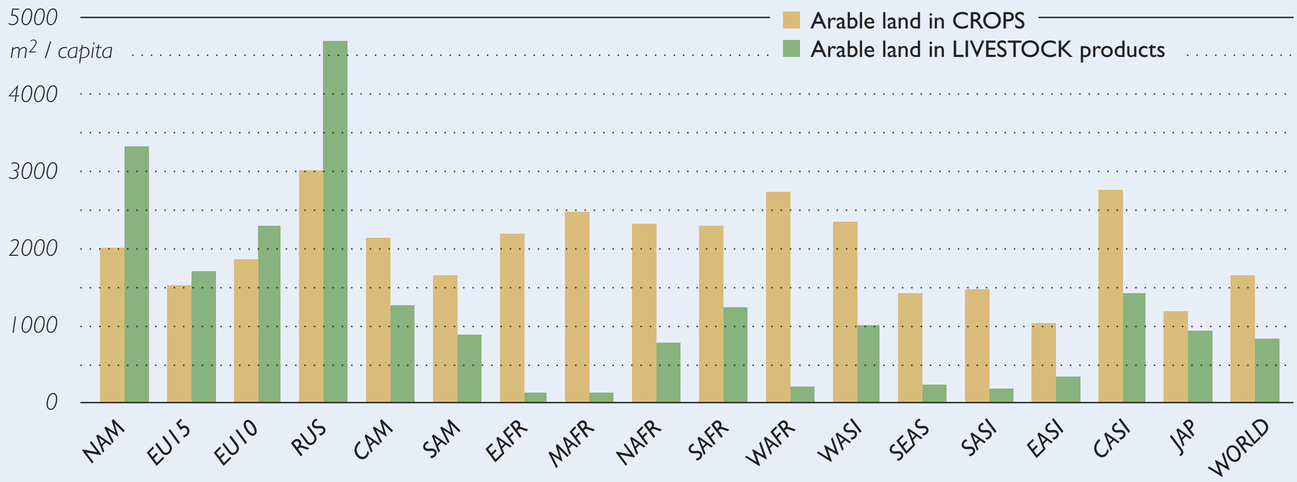
Regional net utilization of arable land (2000-02) Figure 2.5 - 2



Source: Calculations by authors based on FAOSTAT 2008.

Regional per capita cultivated land associated with crop and livestock products (FAOSTAT data for 2000-02)

Figure 2.5 - 3



Source: Calculations by authors based on FAOSTAT 2008.

Approximately 9 percent of cultivated land is associated with *net* exports of agricultural commodities from developed to developing countries; including primary and processed crop products, and livestock products.

Cultivated land used for feed production shows significant regional differences in per capita cultivated land use (Figure 2.5-3). Global average land use for livestock production is 600 m^2 per capita. Regional values vary widely due to differences in both consumption patterns and production efficiency. In North America, Europe, and Russia approximately 3200, 1500, and 4600 m^2 per capita is used for producing livestock feed, respectively. In South Asia, Southeast Asia, and East Asia, per capita use of cultivated land for livestock is less than 300 m^2 per capita. In developing countries the extent of cultivated land used for livestock feed has recently increased significantly owing to dietary shifts towards livestock products, notably in China.

Figure 2.5-4 provides a regional overview of cultivated land associated with net supply and use of agricultural products. Areas associated with *supply* (labeled SUP in Figure 2.5-4) comprise cultivated land used by a region's agricultural sector for crop and livestock feed production ('Production'), the 'foreign' land associated with imported crops and crop products ('Import crops'), and areas associated with imported livestock products ('Import livestock). Cultivated land associated with domestic utilization (labeled USE in the figure below) includes five elements: (a) 'Crops direct' - denoting cultivated land associated with a region's direct human use of crop production (both domestic and imported); (b) 'Livestock' - refers to the cultivated area associated with the consumption of livestock products (domestic and imported); (c) 'Seed and waste' (see above); (d) cultivated land associated with the export of crops ('Exports crops'); and (e) cultivated land associated with the export of livestock and livestock products ('Export livestock').

Comparison of areas associated with imports and exports ('virtual cultivated land') reveals three regions, with 'net exports' of cultivated land. These are North and South

America, and Oceania. Central America, Asia, Africa, and Europe are 'net importers' of cultivated land.

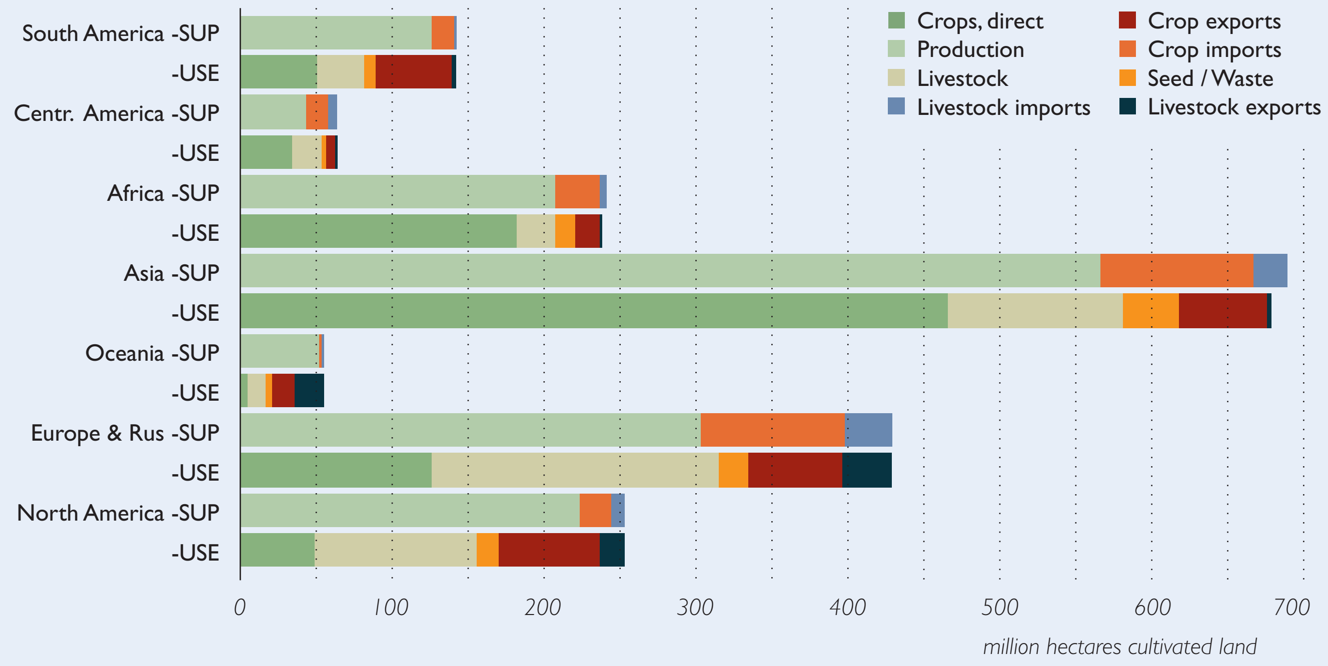
Land associated with biofuel production

Feedstock use for biofuel production is a recent development (apart from the sugar cane based ethanol production in Brazil). Table 2.5-1 indicates the global significance of agricultural land use associated with the production of biofuels in 2007. The information provided refers to harvested areas of six important crops that are also used as major biofuel feedstocks (sugar cane, maize, rapeseed, soybeans, oil palm, and cassava). In 2007, just over 20 percent (330 million hectares) of total cultivated land was used for these crops. Of this, approximately 25 million ha (or 7 percent) was used for biofuel production.

Compared to the total of approximately 1565 million hectares of cultivated land globally, the use of only 25 million hectares (less than 2 percent) for biofuels appears relatively small. However, global biofuel production has tripled since 2000 and reached 36 Mtoe in 2007, accounting for approximately 1.8 percent of road transport fuels. The share of biofuels is projected to reach 4-10 percent of total transport fuel use by 2030 (for details of biofuel scenarios see chapter 3.3), meaning that the cultivated land needed for biofuel production may increase to approximately 65-150 million hectares (i.e., 4-9 percent of total cultivated land). The area required for future biofuel production will depend on both the biofuel production chain and type of feedstocks used. Land use productivity of second-generation biofuel production chains, relying on herbaceous and woody lignocellulosic feedstocks, are expected to show a substantial improvement over most first-generation land use efficiencies.

Cultivated land associated with regional net supply (SUP) and utilization (USE) of crop and livestock products in 2000-2002

Figure 2.5 - 4



Source: Calculations by authors based on FAOSTAT 2008.

Role of biofuel feedstocks in global land use in 2007 Table 2.5 - 1

	Cultivated Land	Harvested area of six* major crops used for food, feed and biofuels		Harvested area of six major crops for producing biofuel feedstocks only	
	Mill. ha	*Mill. ha*	*%*	*Mill. ha*	*%*
North America	230	75	33	11.4	5.0
Europe & Russia	305	24	8	7.2	2.4
Oceania & Polynesia	53	2	3	0.4	0.8
Asia	559	105	19	1.8	0.3
Africa	244	48	20	0.2	< 0.1
Central Amer. & Carib.	43	12	28	0.2	0.5
South America	129	71	55	4.0	3.1
Developed	591	101	17	18.9	3.2
Developing	972	237	24	6.2	0.6
World	1563	338	22	25.1	1.6

Source: Calculation by authors

* Sugar cane, maize, cassava, oil palm, rape and soybean

2.5.2
Greenhouse gas emissions

The combination of improving energy security and providing support to rural economies has been motivating biofuel development in several countries. An additional factor is the growing need to reduce greenhouse gas emissions to mitigate climate change.

Global greenhouse gas emissions in 2006 was 45 Gt in CO_2-equivalent, of which some 62 percent is energy-related (IEA, 2008a). Globally, the transport sector contributed 6.4 Gt CO_2-equivalent in 2006 accounting for 14 percent of total anthropogenic emissions and

World anthropogenic greenhouse-gas emissions in 2006 Table 2.5 - 2

Gt CO2-equivalent	World	OECD	Non-OECD
Total anthropogenic emissions	45.0	18.4	25.6
Energy-related, of which	27.9	12.8	14.1
- Power generation	11.4	4.9	6.5
- Transport	6.4	3.5	2.0
- Industry	4.6	1.5	3.1
- Other energy-related	5.5	2.9	2.5
Non-energy related	17.1	5.6	11.5

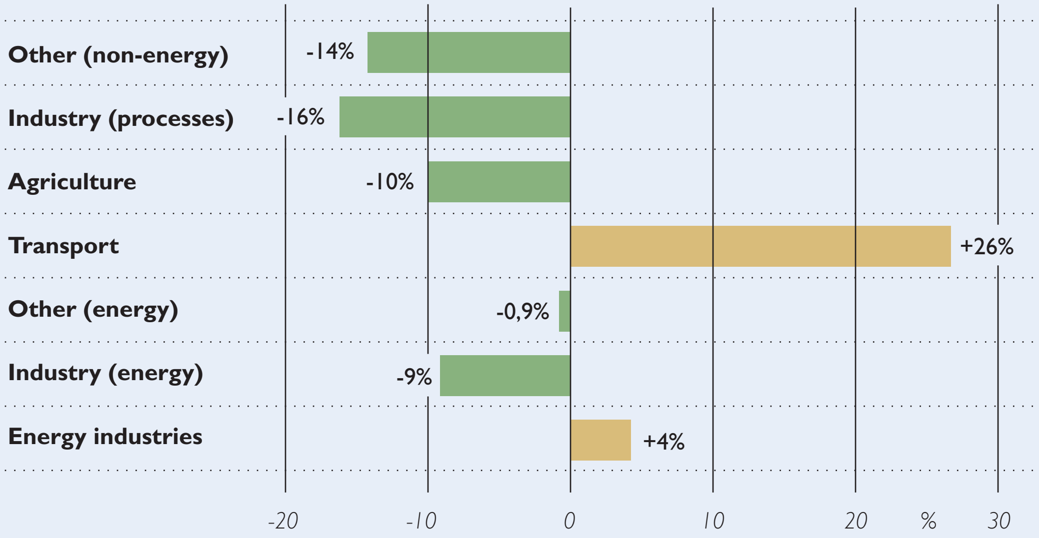
Source: IEA (2008a)

23 percent of energy-related emissions (Table 2.5-2).

Among the main greenhouse gas emitting sectors, energy use for transport is one of the major challenges in the future. Transport is projected to maintain its current growth rate inducing several environmental impacts, of which increased greenhouse gas emissions is one. For example, in the European Union, greenhouse gas emissions declined both overall and in most sectors during 1990–2004, however, emissions from the transport sector increased by more than 25 percent (see Figure 2.5-5).

The CO_2 released through combustion matches the carbon absorbed by the plants from the atmosphere through photosynthesis. In addition, growing biomass may increase soil carbon stocks. Bioenergy has therefore significant potential for emission reductions by substituting fossil fuels. Research is showing that actual net impacts on greenhouse gas emissions may vary significantly. Greenhouse gases are emitted at all stages, from 'cradle to grave', of the biofuels production chain: from the fuel used for the production, harvesting, collection and transportation of bioenergy feedstocks; in the energy required for producing fertilizers and pesticides; during chemical processing of feedstocks; during the distribution of biofuels to end users, and through its final use. For example, nitrous oxide (N_2O), a greenhouse gas with a global warming potential around 300 times greater than that of CO_2, is released from nitrogen-based fertilizers and is a major contributor of greenhouse gas emissions from agriculture (Crutzen *et al.*, 2008; Zah *et al.*, 2007; IPCC, 2006). N_2O emissions also illustrate the great difficulties involved in estimating greenhouse gas balances of biofuel feedstocks as available data reveal a very wide range of outcomes depending on the biophysical setting, i.e. climatic conditions and soils characteristics, on field management practices, and types and timing of chemical fertilizers applied.

Change in GHG emissions 1990-2004 in the EU-15 Figure 2.5 - 5



Source: REFUEL, 2008.

Greenhouse gases can also be emitted or sequestered by direct or indirect land use changes. Greenhouse gas emissions can occur when carbon stored in forests or grasslands is released during land conversion to crop production. Conversion of grassland to cultivated land can release 300 tons of carbon per hectare, and conversion of forestland can release 600–1000 tons of carbon per hectare (Fargione *et al.*, 2008; The Royal Society, 2008; Searchinger, 2008). On the other hand, converting degraded savannas for sugar cane production, or jatropha cultivation, may increase below-ground carbon stocks.

Life-cycle analysis (LCA) is well established as an appropriate technique to analyze systematically each component of the biofuel production chain and to estimate respective greenhouse gas emissions. A necessary starting point in estimating greenhouse gas balances is to define a set of boundaries for a specific biofuel system, which is then compared with a fossil reference system. For transport biofuels, the chosen reference systems are typically gasoline and fossil diesel when comparing different bio-ethanol and biodiesel production systems, respectively.

At present, a number of different methods are being used for life-cycle analysis. The parameters measured, and the quality of the data used in the assessment, need to comply with set standards. There is a similar need for harmonization in assessing the broader environmental and social impacts of bioenergy crops (FAO, 2008a; European Commission, 2008).

A further complication arises from the fact that most biofuel feedstocks also generate by-products, such as distillers' dry grain (DDG) in ethanol production, or protein-rich cakes and meals from biodiesel production. These are considered 'avoided' greenhouse gas emissions when computing greenhouse gas balances of biofuel feedstocks. Different methods and assumptions have been applied in life-cycle assessments of biofuels to account for these by-products, e.g. by comparing them with similar stand-alone products, or by various allocation methods (e.g. by using energy content or market value share as weighting factors) to attribute greenhouse gas emissions at different stages of the production chain to the relevant by-products. By-products also occur in the energy system depending on whether feedstocks are converted to fuel only or whether co-generation techniques produce liquid fuels as well as useful heat and electricity in the conversion process. Finally, large differences result from different conversion processes depending on whether fossil inputs are required for the process or residual plant materials, such as straw or waste, are used as energy sources for the conversion process.

Consequently, greenhouse gas balances published in the available literature differ widely among crops, locations, and conversion technologies, as well as the allocation methods used in accounting for by-products, and specific assumptions about energy sources used in the production of agricultural inputs (e.g. energy source and efficiency of fertilizer production), and feedstock conversion to biofuels. Most life-cycle analyses of biofuels have been undertaken for cereals, sugar beets, and oilseeds in the EU and the United States of America, with several studies for sugar cane ethanol in Brazil. Apart from Brazilian sugar cane, there are few studies available that address feedstocks suitable for conventional biofuel production in tropical countries, such as biodiesel production from oil palm or jatropha, or ethanol production from tropical starch crops like cassava and sweet potato.

Due to the factors discussed above, there is indeed a wide range of results cited in the literature. Nevertheless, when excluding emissions due to direct or indirect land use changes caused by biofuel feedstock production, the majority of studies conclude that producing biofuels from current feedstocks via efficient first-generation conversion processes results in some emission reductions, typically in the range of 20–60 percent relative to fossil fuels.

Maize-based ethanol production is the poorest performer, in terms of greenhouse gas savings, with results ranging from zero savings (or even some losses) up to 40 percent savings compared to using fossil gasoline. A savings value of 20 percent is typically used in assessments (IEA, 2006; WWI, 2007; FAO, 2008a).

Greenhouse gas savings calculated for ethanol produced from wheat (30–55 percent) or sugar beets (35–55 percent) are in the middle range. Savings in the range of 40–60 percent and 50–80 percent are typically cited for biodiesel based on rapeseed and palm oil respectively (IEA, 2006; FAO, 2008a). A notable exception is Brazilian ethanol from sugar cane where estimated greenhouse gas savings, excluding carbon impacts of land use changes, fall in the range of 80 to more than 100 percent. This high level of greenhouse gas savings is because most energy used in the conversion process is derived from sugar cane residues and by-products as well as through co-generation of electricity (e.g., FAO, 2008a; Macedo *et al.*, 2008).

Results for second-generation biofuels based on lignocelluloses biomass conversion are often based on theoretical calculations or scarce empirical data due to the infancy and expected significant further development of these conversion pathways. Typically, emission reductions from cellulose-derived ethanol or F-T diesel are expected in the order of 70–90 percent compared with fossil gasoline and diesel. Several recent studies have concluded that the most marked differences in results and uncertainties of calculations derive from: (i) assumptions regarding land-use related carbon emissions; (ii) allocation methods chosen for dealing with by-products; and (iii) specific assumptions and factors used for calculating N_2O emissions associated with fertilizer use (FAO, 2008a; Crutzen *et al.*, 2008).

Fargione *et al.* (2008) report that soil and plant biomass are carbon stores containing about 2.7 times more carbon than the atmosphere. Land use changes, in particular conversion of natural habitats to cropland, can cause significant changes in respective carbon pools. The authors termed the CO_2 released in the first 50 years of a conversion as the 'carbon debt' of a particular pathway and they calculate a 'payback time', i.e. how many years of biofuel production from such a system that would be required to compensate for the carbon debt of the associated land use change. While future ethanol production from prairie biomass (e.g. second-generation ethanol switchgrass) has a payback time of 1 year or less, expanding sugar cane production in the Brazilian wooded Cerrado would require 17 years to compensate for the carbon lost due to the land conversion. Examples of extremely counter-productive outcomes in terms of greenhouse gas savings would be conversion of tropical rainforest for soybean-based biodiesel (calculated payback time of more than 300 years) and converting rainforests on peat land in tropical south east Asia to oil palm plantations for biodiesel with a calculated payback time of 423 years (Fargione *et al.*, 2008).

The increases in future demand for food, feed, or energy biomass crops will be met by a combination of productivity increases (especially crop yields) and by clearing and converting land to cultivated land. The latter results in increased greenhouse gas emissions. Indirect land use changes resulting from increased biofuel feedstock production are at the center of controversial discussions on increased biofuel deployment. Additional demand for biofuel feedstocks may trigger food and feed production being pushed into forest or grassland due to limited land availability. Searchinger *et al.* (2008) argue that when including greenhouse gas emissions from indirect land use, maize-based ethanol does not reduce emissions but leads to a significant increase in comparison to fossil gasoline. Land use conversions of grassland or forests to arable land are also of particular concern for loss of biodiversity.

As a result of these studies, which take land use changes into account, most biofuels are still considered an important option for reducing greenhouse gas emissions, provided major carbon debts due to land conversion are avoided. However, in many cases improving energy efficiency and conservation, increasing carbon sequestration through reforestation, or using other forms of renewable energy can be much more cost-effective. It is therefore questionable whether achievable greenhouse gas reductions, especially of most currently available first-generation biofuel production routes, can justify the large amount of subsidies and market distortions currently applied to encourage biofuel development (FAO, 2008a).

A comprehensive understanding of the relevant issues, including land use change, and proper assessment of greenhouse gas balances, is essential to ensure that bioenergy crops have a positive and sustainable impact on climate-protection efforts. Some countries and regional organizations (e.g. the United States of America and the EU) have recently proposed that minimum net greenhouse gas balances of biofuels should be at least in the range of 35–40 percent.

In a recent study of the Advisory Council on Global Change to the German Government a number of bioenergy systems were defined and a rigorous methodology was applied to assess life-cycle greenhouse gas emissions in comparison to applicable fossil reference systems (WBGU, 2008; Fritsche & Wiegmann, 2008). The methodology includes calculation procedures to account for direct, as well as (much debated) indirect, land use effects. Impacts of *direct land use changes*, along the lines discussed above, account for changes in terrestrial carbon pools when natural habitats, or previously unused or differently used land, is converted to biofuel feedstocks production. *Indirect land-use changes* can result from bioenergy production displacing services or commodities (food, fodder, fiber products). The demand served by the land use prior to conversion to biofuel production generally continues to exist requiring that other tracts of land (possibly even in other world regions) be used for production. Converting grassland being used as pasture to cropland for biofuel feedstocks production will result in a direct land use change impact due to differences in the soil carbon content of pastures versus cropland. In addition, the foregone fodder, previously obtained from the pasture, must be replaced by alternative feed sources (e.g. converting other habitats to grazing or cultivation of fodder crops), or the foregone livestock products must be replaced by livestock production elsewhere. Carbon debts and greenhouse gas impacts associated with production displaced in this way are difficult to quantify.

There are two research approaches being pursued. The first is to apply a general equilibrium approach that aims to capture indirect land use changes by modeling responses of consumers and producers to price changes induced by competition of biofuel feedstock production with conventional uses (food, fiber, etc) of available resources. The advantage of this approach is that it not only permits modeling land use changes but also considers production intensification on existing agricultural land as well as consumer responses to changing availability of commodities. On the negative side, this approach requires complex analytical tools and results of such analyses can be difficult to communicate and depend on model specification and parameterization.

An alternative method for capturing indirect land use impacts relies on deterministic accounting by stipulating that a certain fraction of displaced services and commodities will be produced elsewhere according to a fixed bundle of alternative production activities. In this approach, the effects subsumed and estimated under the factor of indirect land use changes are quantified according to a simple (yet transparent) set of assumptions (Fritsche & Wiegmann, 2008). However, this method fails to quantify mechanisms other

Greenhouse gas balances of selected liquid transport biofuels Table 2.5 - 3

System	Previous land use	GHG emissions (g CO2 equ./MJ)			GHG emissions (change %)		
		No LU change	*With direct LU change*	*With indirect LU change*	*No LU change*	*With direct LU change*	*With indirect LU change*
Diesel 2005	n.a.	87.9	n.a.	n.a.	0	n.a.	n.a.
WME 2005	n.a.	8.7	n.a.	n.a.	-90	n.a.	n.a.
RME 2005	Cropland	36.5	36.5	92.5-148.6	-58	-58	+5 to +69
RME 2005	Pasture	36.5	66.0	122.0-178.0	-58	-25	+39 to +102
Diesel 2030	n.a.	87.5	n.a.	n.a.	0	n.a.	n.a.
PME 2030	Degraded	45.1	-203.0	n.a.	-48	-332	n.a.
PME 2030	Rainforest	45.1	255.1	n.a.	-48	192	n.a.
JME 2030	Cropland	35.5	35.5	90.0-144.5	-59	-59	+3 to 65
JME 2030	Marginal	35.5	-63.8	n.a.	-59	-173	n.a.
Gasoline 2005	n.a.	91.2	n.a.	n.a.	0	n.a.	n.a.
EtOH-SC05	Cropland	26.5	26.2	59.2-92.2	-71	-71	-35 to +1
EtOH-MZ05	Cropland	40.6	40.6	70.8-101.0	-55	-55	-22 to +11
EtOH-MZ05	Pasture	40.6	56.5	86.7-116.9	-55	-37	-5 to +28
EtOH-WH05	Cropland	46.2	46.2	97.3-148.4	-49	-49	+6 to +63
EtOH-WH05	Pasture	46.2	73.1	124.2-175.3	-49	-20	+36 to +92
Gasoline 2030	n.a.	89.4	n.a.	n.a.	0	n.a.	n.a.
EtOH-SC30	Cropland	22.4	22.2	47.2-72.3	-75	-75	-47 to -19
EtOH-SC30	Savannah	22.4	94.8	n.a.	-75	+6	n.a.
EtOH-SC30	Degraded	22.4	3.8	n.a.	-75	-96	n.a.
EtOH-LS30	n.a.	16.1	n.a.	n.a.	-82	n.a.	n.a.

Source: Fritsche & Wiegmann (2008)

Note: Diesel 2005= fossil reference diesel system, 2005 conditions; WME 2005= Methyl ester from waste vegetable or animal oils, 2005 conditions; RME 2005= rapeseed methyl ester, 2005 conditions; Diesel 2030= fossil reference diesel system, 2030 conditions; PME2030= pal oil methyl ester, 2030 conditions; JME 2030= jatropha oil methyl ester, 2030 conditions; Gasoline 2005= fossil reference system, Otto engine 2005 conditions; EtOH-SC05= ethanol from sugar cane, Brazil 2005 conditions; EtOH-MZ05= ethanol from maize, 2005 conditions; EtOH-WH05= ethanol from wheat, 2005 conditions; Gasoline 2030= fossil reference system, Otto engine 2030 conditions; EtOH-SC30= ethanol from sugar cane, Brazil 2030 conditions; EtOH-LS30= lingo-cellulosic ethanol from straw, 2030 conditions

than land use changes that may substitute for production displaced by biofuel feedstock cultivation.

Table 2.5-3 provides a summary of results of greenhouse gas balances for transport fuels presented in Fritsche & Wiegmann (2008). The estimates are given for a specified reference system based on 2005 data, as well as projected future conditions referring to 2030. Estimates are provided separately for: (i) life-cycle analysis results excluding land use changes; (ii) greenhouse gas balance impacts caused by direct land use changes; and (iii) greenhouse gas impacts of indirect land use changes as calculated by the deterministic method applied in the study (Fritsche & Wiegmann, 2008). Due

Disaggregated default greenhouse gas emissions for selected biofuels Table 2.5 - 4

Biofuel production system	Greenhouse gas emissions from: (CO_2 eq./MJ)				Implied GHG saving* (%)
	Cultivation	*Processing*	*Transport and distribution*	*Total emissions*	
Wheat ethanol (process fuel not specified)	19	63	2	84	0
Wheat ethanol (lignite, in CHP plant)	19	63	2	84	0
Wheat ethanol (natural gas, conventional boiler)	19	35	2	56	33
Wheat ethanol (natural gas, in CHP plant)	19	25	2	46	45
Wheat ethanol (straw, in CHP plant)	19	7	2	28	67
Maize ethanol, (natural gas in CHP plant)	20	21	2	43	49
Sugar beet ethanol	13	38	3	54	35
Sugar cane ethanol	13	1	8	22	74
Rape seed biodiesel	22	22	1	53	36
Sunflower biodiesel	18	22	1	41	51
Palm oil biodiesel (process not specified)	18	47	5	70	16
Palm oil biodiesel (process with no methane emissions at oil mill)	18	18	5	41	51
Waste vegetable or animal oil biodiesel	0	18	1	19	77

Source: Commission of the European Communities, 2008 Note: The default value used as the fossil comparator is 83.8 g CO_2 equivalent/MJ.

to the admitted uncertainty of the indirect land use change impacts two estimates are provided, assuming alternative levels for the capacity of the overall system in responding to displaced production by means other than land use changes (e.g., intensification, substitution of commodities).

There is a need to formalize and harmonize the calculation procedures of greenhouse gas impacts of biofuels, and to discourage land use changes with risky carbon impacts and likely harmful consequences for biodiversity, is addressed in a proposal for a 'Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources' (EC, 2008) presented by the Commission in January 2008.

The proposal included a two-pronged approach: (i) banning production of biofuels from land with recognized high biodiversity value (undisturbed forests, nature protection areas, and grasslands identified as highly biodiverse) and from land with high carbon stocks (wetlands and continuously forested areas), and (ii) defining a procedure and providing default values for calculating greenhouse gas savings for several biofuel production pathways. The default values apply to biofuels produced with no net carbon emissions from land use change, and it is proposed that they can be applied to either feedstocks produced outside the Community, or on land in the Community (this land is to be inventoried at NUTS 2 level) where the default values can be expected not to be exceeded when producing agricultural raw materials. A selection of default values listed in the proposal is summarized in Table 2.5-4.

The environmental impacts of biofuel production chains in general, and consequences for greenhouse gas emissions in particular, vary widely across feedstocks, geographical setting, and farming systems. Future outcomes will critically depend on whether sustainable land use practices can be ensured and globally accepted sustainability criteria can be established and implemented.

Studies clearly show that greenhouse gas balances are not positive for all currently used feedstocks and growing conditions. Greenhouse gas emissions occur at all stages of the production chain, with decisive factors being land conversion, input use and farm practices at the stage of feedstock production. From a greenhouse gas perspective (as well as biodiversity viewpoint) production of biofuel feedstocks must stay away from carbon-rich natural habitats, in particular from remaining natural forests and wetlands.

The cultivation of perennial biofuel feedstocks on reclaimed marginal or degraded land may generate significant additional greenhouse gas savings. Plant residues, wastes, and by-products can provide energy for the conversion process rather than using fossil fuels, and is increasing process efficiency by co-generation of heat and/or electricity which in addition improves the greenhouse gas balances of biofuel production.

2.5.3

Water requirements and water quality

Water is a key driver of agricultural production and its most precious input. Since the beginning of crop cultivation over 10,000 years ago, irrigation water has helped farmers to increase crop yields by reducing their dependence on rainfall patterns. Today, irrigated area has expanded to over 270 million ha worldwide, approximately 18 percent of total cultivated land. Agriculture is the largest user of water among human activities; irrigation water withdrawals are 70 percent of the total anthropogenic use of renewable water resources – approximately 2630 billion m^3 per year in 2000 out of a total of 3815 billion m^3 per year (see Table 2.5-5). An estimated 50 percent of agricultural water withdrawals reach the crops with the remainder lost in irrigation infrastructures. Irrigated crops produce approximately 40 percent of total agricultural output with yields typically 2 times higher than those of rain-fed crops. For example, the FAO estimated that each year irrigated cereals produce approximately 60 percent of the total of 1.2 billion tons in developing countries (FAO, 2003); globally-averaged irrigated cereal yields for developing countries are 3.9 tons per ha, compared to roughly 1.8 tons per ha of rain fed yields (FAO, 2003).

Fischer *et al.* (2006) analyzed changes in global and regional agricultural water demand for irrigation within a long-range socio-economic scenario developed at the International Institute for Applied Systems Analysis (Riahi *et al.*, 2006). Future regional and global irrigation water requirements were computed as a function of both projected irrigated land and climate change and simulations were performed from 1990 to 2080. Future trends for the extent of irrigated land, irrigation water use, and withdrawals were computed (Table 2.5-5).

By 2050, projected global irrigated land is estimated to have increased to 356 million hectares, up from 271 million ha in 2000. Projected agricultural water withdrawals are projected to grow from 2630 km^3 in 2000 to 2924 km^3 in 2030 and to 3090 km^3 in 2050, increases of 11 and 17 percent, respectively, compared to 2000. Climate change and associated warming may add to these requirements an additional 5–9 percent in 2030 and 8–10 percent by 2050. Water demand for food production alone will increase substantially in the coming decades and is likely to aggravate water scarcities in several regions.

Water use of biofuel feedstocks

While biofuels are estimated to have had little share on global crop water uptake in 2005 (de Fraiture *et al*., 2007 and 2008), an accelerated expansion of biofuel feedstock production could easily place additional stress on water supply, especially if irrigated feedstock production is practiced in water-scarce regions. According to the estimates given in Table 2.5-6, in 2005 there were 10 million ha used for cultivation of ethanol feedstocks, mainly sugar cane in Brazil, India, and South Africa, and maize in the United States of America and China. Bio-ethanol feedstocks accounted for an estimated 1.4 percent of total evapotranspiration of agricultural crops and for about 2 percent of irrigation water withdrawals. It can be noted that bio-ethanol production in 2008 was almost twice the level shown for 2005 in Table 2.5-6. Irrigation water use for agricultural feedstocks used for biodiesel production has been negligible as more than half of global biodiesel was produced in Europe, mostly from rain-fed rapeseed.

The International Water Management Institute recently noted that “globally, there is enough water to produce both food and biofuel. But, in countries where water is already scarce, like India and China, growing biofuel

Projections of a world food system reference scenario Table 2.5 - 5

Without climate change of: (a) net irrigation water requirements (km^3); and (b) agricultural water withdrawals (km^3)

Region	Net irrigation water requirements (km^3)			Agricultural water withdrawals (km^3)		
	2000	*2030*	*2050*	*2000*	*2030*	*2050*
WORLD	1350	1630	1773	2630	2924	3090
More Developed	255	274	285	523	508	509
Less Developed	1095	1356	1489	2106	2416	2582
North America	107	125	130	203	216	217
Europe and FSU	151	159	166	304	289	291
Pacific OECD	16	16	18	44	38	39
Africa	45	86	121	91	161	218
Latin America	82	125	150	187	271	318
Middle East	169	195	212	254	267	281
Centrally Planned Asia	213	243	250	496	514	514
South Asia	496	595	633	852	951	986
Southeast Asia	65	78	85	185	202	212

Note: Net irrigation water requirements is defined herein as the amount of water - in addition to available soil moisture from precipitation - that crop plants on irrigated land must receive to grow without water stress. Agricultural water withdrawals increase less than estimated crop water requirements because it is assumed that irrigation water efficiency will significantly improve by 2080.

Source: Fischer et al. (2006)

Water use for cultivation of bio-ethanol feedstocks in 2005

Table 2.5 - 6

Country	Bio-ethanol	Feedstock	Harvested area	Bioenergy in harvested area	Evapo-transpiration	Bioenergy feedstocks in evapotranspiration	Irrigation water withdrawals	Bioenergy in irrigation water withdrawals
	m^3		*Mha*	*Share in %*	*km^3*	*Share in %*	*km^3*	*Share in %*
Brazil	15098	Sugarcane	2.4	5.0	46.02	10.7	1.31	3.5
United States	12907	Maize	3.8	3.5	22.39	4.0	5.44	2.7
China	3649	Maize	1.9	1.1	14.35	1.5	9.43	2.2
India	1749	Sugarcane	0.3	0.2	5.33	0.5	6.48	1.2
France	829	Sugar beets	0.2	1.2	0.90	1.8	-	0.0
South Africa	416	Sugarcane	0.1	1.1	0.94	2.8	1.08	9.8
UK	401	Sugar beets	0.1	2.4	0.44	2.5	-	0.0
Spain	299	Wheat	0.3	2.2	1.31	2.3	-	0.0
Thailand	280	Sugarcane	0.0	0.3	1.39	0.8	1.55	1.9
Germany	269	Wheat	0.1	1.1	0.36	1.2	-	0.0
World	36800		10.0	0.8	98.00	1.4	30.6	2.0

Source: de Fraiture et al. (2008)

crops will intensify existing problems” (IWMI, 2008).

However, there are large differences in water requirements of different feedstocks as well as major location-specific differences in the amount of water available from precipitation and irrigated water resources. Consequently, required irrigation water per liter of bio-ethanol produced may vary vastly across different locations (Table 2.5-7).

Impacts of biofuel production on water resources largely depend on making appropriate choices of suitable feedstocks to be cultivated and appropriate management practices. Promoting sugar cane production in water-scarce environments may cause environmental damage, as recently reported by McCornick *et al*. (2008) for the Krishna Basin in India. The use of sweet sorghum or jatropha, with lower water requirements than sugar cane, could

Irrigation water required for ethanol production

Table 2.5 - 7

Country	Biofuel feedstock	Irrigation water use: *litre-water / litre-ethanol*
Brazil	Sugarcane, mostly rainfed	90
United States of America	Maize, mostly rainfed	400
Northern China	Maize, partly irrigated	2400
India	Sugarcane, irrigated	3500

Source: de Fraiture et al. (2008)

create opportunities for rain-fed cultivation, albeit with significantly lower yields. To minimize water competition with food production, as well as to safeguard maximum greenhouse gas savings of biofuel use, producing biofuel feedstocks under irrigated conditions should be discouraged and feedstocks appropriate for rain-fed cultivation should be used.

Regardless of biofuel production, perhaps the most effective way to deal with an increase in demand for water is to improve the water productivity of agriculture, i.e. finding ways of producing more crop output per unit of water expended (IWMI, 2008).

Water pollution

Producing more biofuels will affect not only water quantity but also water quality, both through run-off of agro-chemicals, as well as through harmful substances produced in feedstock processing and conversion. Although not specific to biofuel feedstocks, the enhanced competition for agricultural resources due to biofuel feedstock production may add to the risks of intensifying environmental pressures created by overexploitation of resources, poor farming practices, or increased cycling of nutrients and pollutants exceeding the buffering and self-cleaning capacity of biological systems.

It is well established that maize requires more fertilizer and pesticides than most other food crops. As such, a large expansion of maize-based ethanol production, as has been taking place in the United States of America, increases the risk of groundwater contamination, reduces water quality, and causes eutrophication of water bodies.

Water pollution was a severe environmental problem in sugar cane producing regions in Brazil until the early 1980s when legislation was implemented to ban the direct discharge of vinasse (Martinelli and Filoso 2008; Smeets *et al*. 2008). The main industrial sources of pollutants from sugar cane treatment are wastewater from washing of stems before processing and vinasse produced during distillation. These by-products cause water contamination due to high concentrations of organic matter, which increase the biochemical oxygen demand (BOD_5) of water bodies. (Gunkel *et al*. 2007). Strict regulation and control of the disposal of nutrient-rich waste from industrial processes (e.g. vinasse) is required to avoid deterioration of water quality (Gunkel *et al*. 2007). Recycling of sugar cane by-products in the fields reduces chemical fertilizer application rates but with a risk of excess application close to processing plants (Smeets *et al.* 2008).

Various technologies have been identified to immediately increases the efficiency and sustainability of current and future sugar cane mills, e.g. reducing water consumption through closure of water-processing circuits and the use of bagasse (fibrous residue left after cane milling) to generate electricity, improving the energy balance of ethanol production; as well as in production and harvesting processes. Water recycling rates in Brazilian sugar cane mills have increased from approximately 63 percent in 1990 to 88 percent by 2005 (Elia Neto, 2008).

Adequate know-how and well-developed technology is available to achieve sustainable sugar cane production and expansion (Goldemberg *et al*. 2008). However, the adoption of new technologies requires a favorable economic and political environment that facilitates investments in clean technologies. While Brazil has accumulated considerable experience on sustainable sugar cane production, it will be critical to share and transfer this knowledge and ensure application of new technologies and 'best practice' within Brazil, in other regions of the Americas, Asia, and especially Africa.

It is important to point out that the deployment of biofuel feedstock systems not only creates additional environmental risks but may also spawn new opportunities for better environmental management. Careful selection of feedstocks that match environmental conditions and implementation of 'best practice' in introducing these new cropping systems could enhance the sustainability of agriculture by reducing the application of fertilizers and pesticides and avoiding the need for irrigation water. In this respect, perennials such as jatropha hold great promise to widen the options of farmers especially in semi-arid regions.

Environmental benefits are also reported for woody and herbaceous plants that are expected to become important as lignocellulose feedstocks for second-generation biofuel production. These perennials require less agricultural inputs, and extend and improve the period of vegetation cover. Some woody species, like willow and poplar, can filter the nutrients from agricultural non-point source pollution while producing high yields of biomass. Prudent land use choices could therefore contribute to reducing water pollution and soil degradation and could enhance carbon stocks in degraded and marginal soils while providing energy.

2.5.4

Biodiversity implications

The impact of biofuel productions on biodiversity depends on (i) the land utilization type of the feedstock used (i.e., feedstock specific characteristics together with typical field management practices such as scale of operation, degree of mono-cropping, tillage methods, fertilization intensity, use of agro chemicals to combat pest and diseases, use of GMOs, invasive characteristics of feedstocks etc.), and (ii) the pre-conversion land use or land cover situation. Generally, conversions from natural areas to cultivation of first-generation feedstocks e.g., soybean and palm oil, have the highest impact in terms of loss of biodiversity. Low or no biodiversity losses occur when only the economic purpose changes, e.g. with rape grown for vegetable oil for human consumption or for bio-diesel. On the other hand, positive biodiversity effects can be achieved when converting intensively managed agricultural land to less intensive uses.

The use of GMO feedstocks also has consequences. They may genetically 'contaminate' landraces potentially reducing genetic adaptive capacity, for example the ability to endure specific ecological and biophysical conditions. Another indirect example of the effect of GMOs is illustrated by a soybean variety that is tolerant to herbicides, allowing the farmer to eradicate weeds that compete for nutrients, water, and light and to eliminate possible hosts for pests or diseases. However, it also eliminates the micro and meso-level ecosystems of natural flora and fauna.

Land conversion

Conversion of natural ecosystems (forests and grasslands) generally induces high losses of biodiversity whereas conversion of abandoned agricultural land or extensively used grasslands causes fewer losses. The change from intensively used agricultural land causes least losses or may even have a positive effect on biodiversity. Conversion through mono-cropping without compensation through 'habitat islands' and 'migration corridors' may have a far-reaching negative impact on ecosystem survival around converted land.

Feedstocks

Feedstocks themselves have various environmental implications. Some are grown on a large scale in monocultures with intensive fertilizer applications and the use of biocides to control weeds or combat pest and diseases.

Feedstock specific biodiversity effects

Table 2.5 - 8

Feedstock type	Typical land converted or used	Environmental Problems	Impact on bio-diversity	Premium for bio-fuel
Oil palm	Virgin forest	Monocultures/Irreversible destruction of virgin forest (bush fires)	Very high	High oil yields
Sugarcane	Grassland/ cultivated land	Monocultures/biotech/processing pollution	High	Efficient ethanol production
Maize	Cultivated land	Monocultures/biotech/agro chemicals/erosion	High	Agronomic easy, low efficiency
Cassava	Cultivated land/grassland/ forest land	Competing with use as food crop	Neutral	In testing stage. High expectations
Rape	Cultivated land	Monocultures/biotech/agro chemicals/erosion	High	Simple technology but low efficiency
Soybean	Grassland/cultivated land/ forest land	Monocultures/biotech/agro chemicals/erosion. Direct and indirect intrusion in biodiverse ecosystems	Very high	Agronomic easy, low efficiency
Jatropha	Grassland/cultivated land	Monocultures/socioeconomic and agronomic uncertainties, toxic, invasive. Not domesticated	Neutral	Uncertain relative high oil yields claimed
Switchgrass	Grassland/cultivated land	Monocultures/tall/long rotations/competing with food crops	Neutral to positive	Second generation, high yields, high efficiency
RCG	Grassland/wetland	Monocultures/long rotations. Best on wetland, invasive forms natural monocultures	Mod.high to neutral	Second gen. , moderately high yields, high efficiency, adapted to cold environments
Miscanthus	Grassland/cultivated land	Monocultures/tall/ long rotations	Neutral positive	Second generation, high yields, high efficiency
Willow	Grassland/ woodland/wetland	Best on wetland/ agrochemicals in case of SCR	Mod.high to neutral	Second generation, high yields, high efficiency
Poplar	Grassland/woodland/ cultivated land	Monocultures agrochemicals in case of SSR or SCR (biotech- advanced hybridization)	Mod.high to neutral	Second generation, high yields, high efficiency
Eucalypt	Grassland/woodland	Monocultures/ toxic agrochemicals in case of SCR	Mod.high to neutral	Second generation, high yields, high efficiency

- Monocultures require the inclusion of 'habitat islands' and/or 'migration corridors' to safeguard biodiversity.
- Biotechnology involves uncertainties regarding effects on agro-diversity. It allows for the use of specific herbicides, which may severely impact biodiversity.
- First-generation feedstocks (in particular maize and rape) require substantial fertilization and agro-chemicals for pest and disease control causing environmental impacts (eutrophication) which in turn may affect biodiversity.
- Some feedstocks are aggressive invasion species (in particular jatropha and reed canary grass).
- Monocultures of tall, long rotation feedstocks may significantly alter visual aspects and dynamics of agricultural landscapes - this is the case for second-generation feedstocks. Large tracts with monocultures of maize and sugar cane may have similar effects.
- Reed canary grass invades fragile wetland ecosystems. Willow grows well under (semi) wetland conditions.
- In particular short duration coppice rotation systems and short duration single stem rotations systems (mainly poplar) lead to infectious diseases, which in turn necessitates application of environmental unfriendly fungicides.
- Toxicity of the biofuel feedstocks may impact safe handling of the produce (jatropha) or its toxicity is effectively preventing undergrowth (eucalypt) and directly reducing biodiversity.
- Biotechnology and development of GMOs refer to mainly soybean, rape (canola), maize, poplar and sugar cane (and to some extent to switchgrass). Limited biotechnical developments apply to jatropha (not domesticated), cassava, reed canary grass, miscanthus, willow, and eucalypt.

GMOs may require less input per unit output but may have a devastating effect on biodiversity.

Other feedstocks may be grown under minimum tillage systems and best practice principles such as returning residues and byproducts to the field (instead of using chemical fertilizer) and are by-and-large resistant to pest and diseases (requiring no or little biocides), while providing eco-topes for a diversified and rich fauna and flora.

Management applied

The impact on biodiversity is primarily defined by both environmental regulations and production economy/demand. A lack of environmental legislation and implementation, together with a preference for virgin forestland conditions (for reasons of freely available nutrients in the proper proportions, ideal organic matter status and freedom from pest and diseases), may cause severe environmental damage including loss of biodiversity. The use of virgin forest calls for them being burnt and subsequently: (i) exploiting (mining) nutrients and organic matter; (ii) inducing nutrient losses due to soil erosion; and (iii) compacting topsoils. Together these impacts may render the sites unsuitable for any agricultural use in the long term, while promoting invasion of very few hardy weed types that often are highly inflammable.

'Best practice' management, including nutrient recycling, has shown to be economic and is increasingly being applied for sugar cane production. In addition, there are promising examples of application of best practice management for oil palm in Malaysia.

The application of organic farming methods to the production of first-generation feedstocks in Europe shows little economic promise due to its low productivity and the scale of production. Integration of second-generation biofuel feedstocks into organic farming systems is so far incompatible with the principle objectives of organic farming, such as crop rotation, and the typical scale of operation.

From the above it may be concluded that biodiversity effects are feedstock specific and are linked to the type and intensity of land conversions and management applied. Table 2.5-8 gives an overview.

2.5.5
Economic and social aspects

Biofuels development to enhance energy security, contribute to greenhouse gas savings, economically compete with fossil fuels and foster higher agricultural incomes and rural employment generation, and in particular to ensure that biofuels production does not take place at the expense of food and feed production are important elements for sustainable social and economic development.

Many developing countries experience food insecurity, and with continuing population growth over the next five decades, food demand will more then double. If there is competition for land and water resources between food and feed, and biofuels, then food security may be threatened, not only at the country level, but also internationally, as world food stocks would be lower in situations where major food exporters divert cereal exports to domestic biofuels industries. For more than three decades, food insecurity affecting over 20 percent of the world's population has been of concern, yet there has been little progress on reducing hunger. We need to ensure that biofuels do not lead to a worsening of this situation.

In 2008, a combination of factors highlighted the vulnerability and risks of food insecurity and hunger. Increased demand for biofuels feedstocks, low levels of world food

Estimates of Ethanol prices in US$/barrel Table 2.5 - 9

US$/barrel	2006	2030*
Price of Oil	50-80	
Ethanol from Sugar Cane	25-50	25-35
Ethanol from Maize	60-80	35-55
Ethanol from Sugar beet	60-80	40-60
Ethanol from Wheat	70-95	45-65
Ethanol from Lignocelluloses	80-110	25-65
Biodiesels from animal fats	40-55	40-50
Biodiesels from vegetable oils	70-100	40-75
Fischer-Tropsch synthesis liquids	90-110	70-85

Source: The Royal Society, 2008

* Long Term projection estimates

stock reserves, increased import demand from major developing countries, and bans on food exports in a number of countries resulted in an escalation of world food prices that resulted in food shortages and increased food insecurity in a number of developing countries.

Despite assertions of the environmental, social, and economic benefits of biofuels, there is currently limited scientific research assessing the socio-economic impacts and consequences of the linkages between the economics and environmental analysis of biofuels production and consumption, food prices and food security, and issues of sustainable development. Existing research tends to focus on the technological economics of biofuels production, the environmental issues of energy balance, and the potential to reduce greenhouse gas emissions. Moreover, very little research has been done on the potential health risk of biofuels production, from the increased use of chemicals and fertilizers in feedstock production and the hazardous pollutants and particulate matter emitted from vehicles using a blend of petroleum and biofuels.

Biofuels are regarded as competitive when the crude oil price exceeds the range of US$ 50–80 per barrel. During the first half of 2008, crude oil prices increased steadily from US$ 85 per barrel in January to US$ 145 per barrel in June and thereafter the price declined, ending at about US$ 40 in December 2008. While the biofuel production costs, current and long-term projected, are higher than mineral oil (Table 2-5-9), these estimates do not take into account other important factors. A full assessment of the competitiveness of biofuels over mineral oil needs to take account of the social and environmental cost and benefits in addition to economic considerations.

Brazil is the country with longest standing and successful biofuels program. The Brazilian program began in earnest in the 1970s with substantial government support. By 2000 the sector had commercialized and sufficiently matured to the extent that it was taken over by the private sector. The Brazilian government dismantled all support measures and incentives. The Brazilian government also decreed and promoted region-wide feedstock production by small farmers. This is particularly important as land distribution in Brazil is characterized by both rich industrial-scale large farmers and poor small-scale family farmers.

The United States of America, Europe, and Brazil have also emphasized an additional underlying development policy thrust: that of increasing agricultural incomes and enhancing rural development. This includes the generation of employment opportunities from increased production of biofuel feedstocks and the establishment of rural biofuel processing industries, as well as biofuel marketing and distribution. Brazil's experience has seen the creation of some 700,000 jobs in the biofuels industry since the mid-1970s. Estimates indicate that the EU biofuels program will generate some 100,000 rural jobs by 2020 and in the case of the USA some 200,000 jobs will be generated.

In all countries, developed and developing, average rural incomes are lower and rural unemployment rates are higher than their urban counterparts are. Moreover, in the developing world, 57 percent of the total population resides in rural areas and this share is projected to decline to 33 percent by 2050. In addition, more than 70 percent of the world's poor and hungry live in rural areas.

Nevertheless, developing countries need to tread cautiously towards developing a biofuel industry as biofuels can result in unpredictable social, economic, and environmental impacts.

Social concerns include the need to share benefits and to ensure participation in decision making processes by local communities. Land tenure issues, and the provision of health and educational services are important. Biofuel programs could result in the concentration of land among large commercial farmers to the exclusion of small farmers. It is important that biofuel development programs give adequate consideration to these issues to ensure benefits flow to local communities, since without this, long-term sustainability will be questionable.

To achieve economic and social sustainability, biofuel programs need to give security of supply, to be price-competitive with fossil fuels, and to ensure access to affordable energy. At the macroeconomic level, the industry should reduce fuel imports, create export potential, generate local employment opportunities, increase rural on-farm and off-farm incomes, and diversify the rural economy.

Some studies have indicated (though not conclusively) that biofuels have the potential to reduce emissions of some toxic substances associated with fossil fuels. Use of biofuels results in lower particulate, carbon monoxide, and sulphate emissions. Use of bio-ethanol can reduce the emission of ozone-forming volatile organic compounds, but it produces higher ethanol and acetaldehyde emissions. Biofuels also show higher emissions of nitrogen oxide. There is need for more research and case studies to assess the potential impacts of biofuels on human health, particularly in urban environments. In rural areas many people rely on traditional biomass fuels and often their cooking environments are highly confined with significant risks of respiratory ailments. Biofuels might contribute to reducing the risks associated with traditional household fuels such as charcoal and fuel wood.

Food security is a major concern since land and water resources are limited in many developing countries. Resources are likely to come under further pressure due to climate change.

Another problem for developing countries relates to existing international trade rules that apply to agricultural commodities. The current situation is that farmers in developing countries are disadvantaged by developed country polices of tariffs, quotas and subsidies. The Doha Round of trade negotiations has so far failed to make progress on reforms, and hence future trade of biofuels is likely to take place in the current environment. It is likely that a few large and massively subsidized developed country producers will capture the bulk of world market trade in biofuels, thus excluding developing countries, which are additionally faced with the challenges of lack of technical knowledge and funds for investment.

Developing countries need to heed such potential barriers to trade and should focus on biofuels production for the domestic market. They need to take strategic steps towards identifying and developing niches in the world biofuels markets by:

- Assessing the country's spatial agro-ecological potential for food production and different biofuels feedstocks, taking into account the impacts of future climate change. Such assessments will establish the extent and productivity of land and water resources available for biofuel feedstock production and hence define the scope, viability, and scale of potential biofuel programs.
- Assessing and monitoring the domestic and world biofuels production and assessing the impacts on food prices, food security, rural incomes and rural energy mix systems to formulate the right mix of social, economic, and environmentally sound policies.
- Developing and promoting standards with an eco-label to create viable niches in the world biofuel markets and remove any domestic barriers that could hinder access to world biofuels markets and further create support incentives for exports.
- Mobilizing finance and access to technology and skilled labor for the development of biofuels programs.

The costs of biofuels programs are large. These include the need for substantial subsidies to the industry (often captured by large scale producers and agro-business), the fiscal and equity impacts of lower government revenues (as a result of tax exemptions for biofuels), the implications for agriculture and agricultural trade policy and the potential environmental damages associated with feedstock production and biofuels manufacturing, as well as human health issues of biofuel use.

For biofuels to be a viable renewable transport fuel blending option they should provide a net energy gain, be producible in large quantities without affecting food supplies, have environmental benefits, be economically competitive, be socially attractive in terms of reducing health risks associated with traditional oil-based transport fuels, contribute to generating rural employment opportunities and increased agricultural incomes, and above all should not result in increased food insecurity.

2.6. Biofuels crops: current situation and trends

First-generation biofuel production from agricultural crops is dominated by two types of fuel, bio-ethanol (used to replace fossil gasoline) and biodiesel (used to replace fossil diesel).

Bio-ethanol is derived from sugar crops (Section 2.6.1) or from crops with high starch content. Production of lipid-based fuels, mainly biodiesel and straight vegetable oils, uses animal fats or vegetable oils derived from various oil crops (see Section 2.6.3).

The easiest and most efficient way to produce bio-ethanol is from feedstocks with high sugar content. When ethanol is produced from starch crops, an extra step is required in the conversion process to break down the starch polymers into sugar. The energy and other input requirements of this extra step in feedstock conversion negatively affects greenhouse gas balances and achievable energy input-output ratios of starch-based ethanol as compared to sugar-based ethanol.

2.6.1
Feedstocks for sugar based ethanol

The most important sugar crop used as ethanol feedstock is sugar cane, due to its high agronomic productivity and well-developed and efficient conversion technologies. In addition, modern sugar cane processing allows producers to be flexible in catering to both sugar and ethanol markets. Due to the outstanding role played by Brazil in developing bio-ethanol production, sugar cane accounted for nearly half of all bio-ethanol produced in 2008.

In cooler conditions where sugar cane cannot be cultivated, such as in Europe, sugar beets have been used to some extent for ethanol production. Sugar beet can also provide relatively high ethanol yields per hectare of cultivated land, however, sugar beet cultivation requires large inputs of energy and agro-chemicals compared to sugar cane. In addition, unlike sugar cane, sugar beets are agronomically not suitable for mono-cropping due to the risk of diseases and pests surviving in soil, meaning that sugar beets have to be incorporated in crop rotations.

Of growing interest in tropical and sub-tropical regions is sweet sorghum, as it can provide large amounts of sugar in the stem as well as grain for food or energy uses. Sweet sorghum is particularly suitable for low rainfall conditions, where it is seen as a viable option for smallholders producing both energy and food.

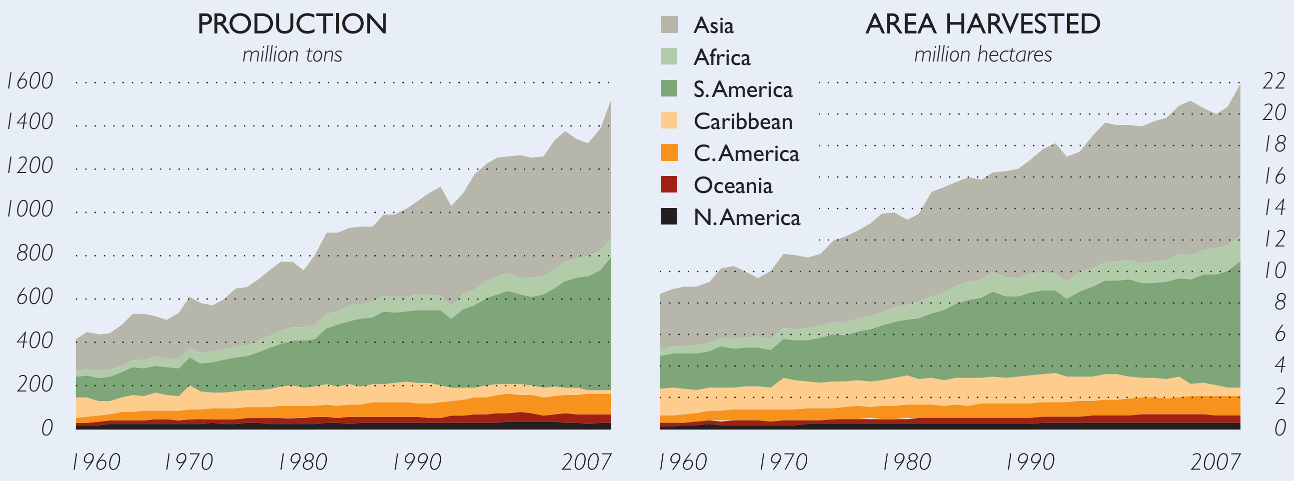
Sugar cane

Historical scale, regional distribution and dynamics of sugar cane production

Sugar cane (*Saccharum*) originates from tropical South- and Southeast Asia. According to the Food and Agriculture Organization (FAO) of the United Nations, world production of sugar cane in the middle of the last century was approximately 260 million tons produced on over 6 million hectares, i.e., an average yield of just over 40 tons per hectare. By 1980, the global harvest of sugar cane had reached 770 million tons cultivated on 13.6 million hectares of land with an average yield of 57 tons per hectare. At present, world sugar cane production is estimated at 1525 million tons from 21.9 million hectares with an average yield of 70 tons per hectare. Figure 2.6-1 shows the time development and broad regional distribution of sugar cane production and area harvested.

Global sugar cane production 1960-2007, by broad geographic region

Figure 2.6 - 1



Source: FAOSTAT, online database at http://www.fao.org, accessed July 2008.

Although the FAO lists more than 100 countries where sugar cane is cultivated, Table 2.6-1 indicates that global sugar cane production is concentrated in only a few countries. The 10 top countries listed in Table 2.6-1 account for more than 80 percent of the sugar cane produced in 2007. During the last 30 years, Brazil became the major producer of sugar cane and today it accounts for about one third of total world production. This development in Brazil

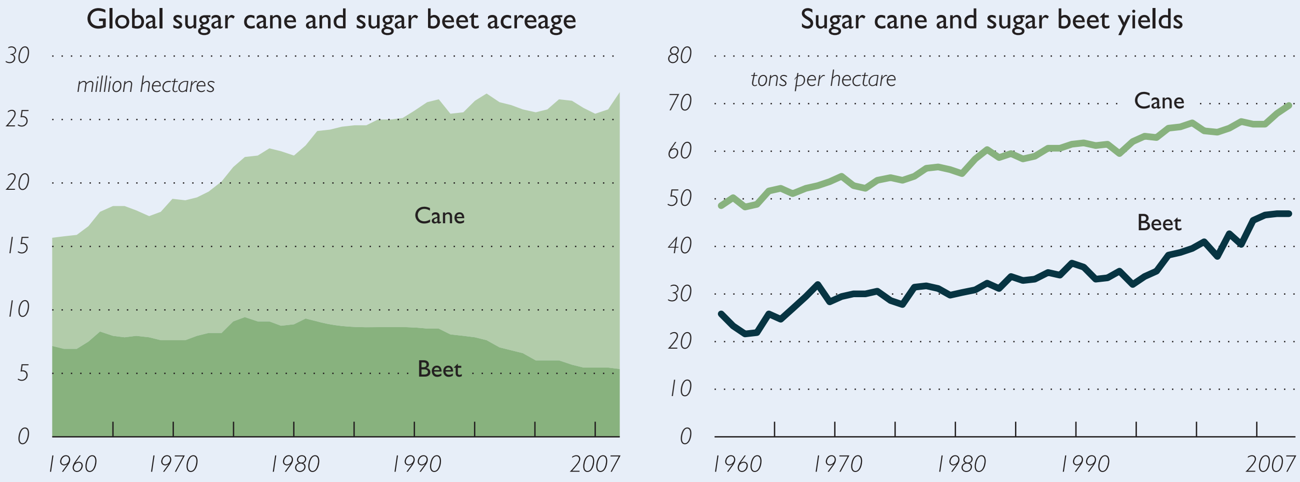
Sugar cane production of major producers, 1961- 2007

Table 2.6 - 1

Production *million tons*	2007	1999-01	1989-91	1979-81	1969-71	1961
Brazil	514	336	259	148	78	59
India	356	297	223	145	129	110
China	106	75	64	34	20	12
Thailand	64	51	37	18	5	2
Pakistan	55	48	36	29	24	12
Mexico	51	46	41	34	33	19
Colombia	40	33	27	25	13	13
Australia	36	35	24	23	18	10
USA	28	32	27	24	21	18
Philippines	25	25	25	31	25	17
Others	283	281	291	256	210	175
World	1,558	1,260	1,054	768	576	448

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008; FAO

Harvested area and yields of sugar cane and sugar beet, 1960-2007 Figure 2.6 - 2



Source: FAOSTAT, online database at http://www.fao.org, accessed July 2008.

has been driven primarily by domestic policies fostering bio-ethanol production to increase energy self-reliance and to reduce the import bill for petroleum. The second largest producer is India, where crystallized sugar, extracted from the sucrose stored in the stems of sugar cane, has been known for more than 5000 years.

The dominance of Brazil in global sugar cane production and expansion – Brazil accounted for 75 percent of sugar cane area increases in the period 2000–2007 and two-thirds of global production increases in that period – derives from its experience and a capability to respond to growing international demand for transport fuels.

Two main factors underlie the dynamics of sugar cane cultivation during the last four decades: a four-fold expansion of sugar cane acreage in South America between 1960 and 2007, and a collapse of sugar cane cultivation in the Caribbean sugar islands, especially in Cuba and Puerto Rico. Solid growth of production and about a three-fold expansion of sugar cane acreage since 1960 occurred in Asia, mainly driven by rapid domestic food demand increases for sugar in China and India. Fuel ethanol production from sugar cane has played a minor role in these dynamics.

An additional factor promoting the global expansion of sugar cane cultivation is the plant's efficient agronomic performance and its comparative advantage relative to sugar beet. While post-war self-reliance policies and protection of agriculture in developed countries supported an expansion of sugar beet cultivation areas until the late 1970s, the last three decades witnessed a gradual decline in harvested areas of sugar beet and increasingly a substitution of temperate sugar beets as a raw material for sugar production with tropical sugar cane (Figure 2.6-2).

Global significance of ethanol production from sugar cane

For most of the 20th century, sugar cane production took place in response to global demand for sugar, was largely conditioned by the heritage of colonial structures, and was greatly influenced by policy and trade agreements. With the launching of the ProAlcool program in Brazil in the mid 1970s, another important

Global significance of sugar cane production in 2007 Table 2.6 - 2

	SUGAR CANE			CULTIVATED LAND	SUGAR CANE HARVESTED	
	Harvested *Million ha*	Production *Million tons*	Yield *Tons/ha*	Total *Million ha*	% of total cultivated land	% harvested for ethanol
North America	0.4	28	77.6	229.3	0.2	0.0
Europe & Russia	< 0.1	< 1	61.4	296.4	0.0	0.0
Oceania & Polynesia	0.5	40	79.9	54.8	0.9	0.0
Asia	9.6	639	66.4	577.1	1.7	< 1.0
Africa	1.6	92	56.8	239.3	0.7	< 1.0
Centr. Amer & Carib.	1.8	114	63.4	42.9	4.2	1.0
South America	8.0	611	76.5	121.9	6.6	45.0
Developed	0.9	67	78.9	580.4	0.1	0.0
Developing	21.0	1457	69.2	981.3	2.1	17.8
World	21.9	1524	69.6	1561.7	1.4	17.1
Brazil	6.7	514	76.6	66.6	10.1	50.0
India	4.8	323	72.6	169.7	2.8	n.a.
China	1.4	106	86.2	140.0	1.0	n.a.
Thailand	1.0	64	63.7	17.8	5.7	3.0
Pakistan	1.0	55	53.2	22.1	4.7	n.a.

Source: FAOSTAT, 2008; F.O. Licht, 2007, 2008; Fischer et al., 2008.

demand factor entered the scene, initially of national importance only. Because of the sugar cane expansion, triggered by the program, Brazil has become the largest sugar cane producer in the world and the largest exporter of bio-ethanol.

Although detailed data on feedstock use are difficult to obtain, it can be concluded that 45–50 percent of the world's fuel ethanol production is based on sugar cane, requiring 280 to 300 million tons of sugar cane from an estimated 3.75 million hectares harvested area (Fischer *et al.*, 2008b).

Table 2.6-2 summarizes the data for 2007. Apart from presenting basic sugar cane statistics, the regional land-use significance of sugar cane is shown in terms of percentage of cultivated land used for sugar cane cultivation. In 2007, just over 10 percent of Brazil's cultivated land served the sugar and ethanol industries. As a consequence, at the regional level, South America shows the highest share in 2007, allocating 6.6 percent of total cultivated land to sugar cane. In comparison, the countries holding rank two and three in global production, India and China, devoted only a small fraction of the resource base to sugar cane, respectively 2.8 and 1.0 percent of cultivated land (Fischer *et al.*, 2008b).

2.6.2

Feedstocks for starch based ethanol

The principal starch crops used as feedstocks for ethanol production include maize, e.g. in the United States of America and China, and wheat, barley, and other minor cereals in temperate Europe, Canada, and Asia.

Apart from cereals, various temperate and tropical root crops contain large amounts of starches. Of particular interest for ethanol production is cassava, which is widely grown in Africa and to a lesser extent in Asia, e.g. in Thailand and China. Due to its ability to grow in marginal areas, cassava is considered as a potential ethanol feedstock in future biofuel production in countries where, due to food security concerns, good land is prioritized for food crops e.g., in China.

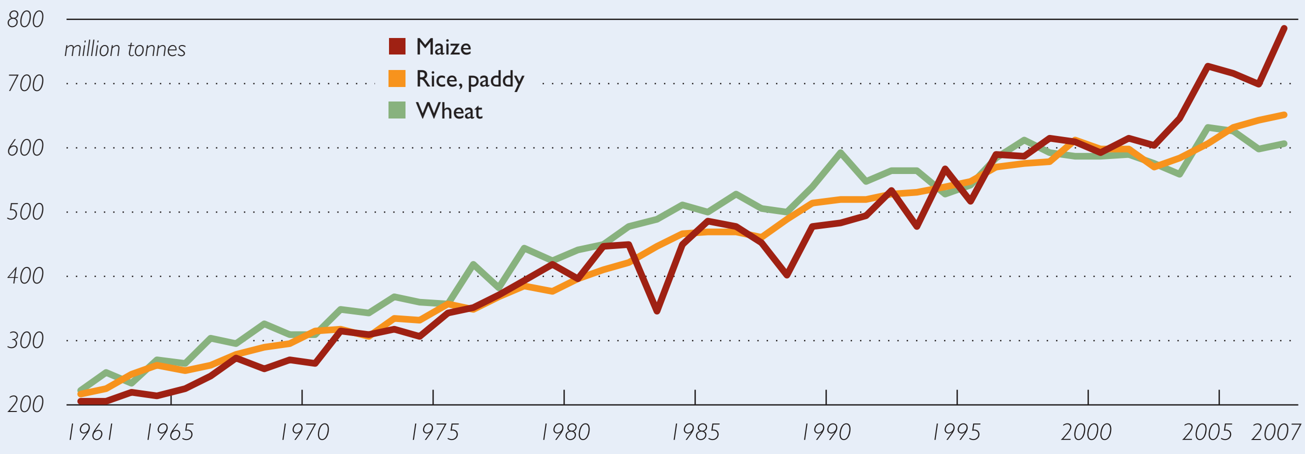
Maize

Historical scale, regional distribution and dynamics of maize production

Maize (*Zea mays*) is a cereal originating from Latin America, where it was domesticated. During early contacts of Europeans with the Americas in the late 15th and early 16th centuries, maize was brought to Europe and was subsequently spread to the rest of the world. Varieties of maize are adapted to both temperate and tropical climates. Maize is the world's largest cereal crop with a production of 785 million tons in 2007, followed by rice (652 million tons), and wheat (607 million tons). Until the late 1990s, wheat still exceeded maize production. After 2003, maize production increased sharply surpassing both wheat and rice (Figure 2.6-3). The recent increases can largely be attributed to the increases in USA maize based fuel ethanol production (compare also Figure 2.6-7).

The United States of America is the largest producer of maize accounting for 42 percent of total world production, followed by China (19 percent), Brazil (6.6 percent), and the European Union (6.4 percent) (Table 2.6-3 and Figure 2.6-4).

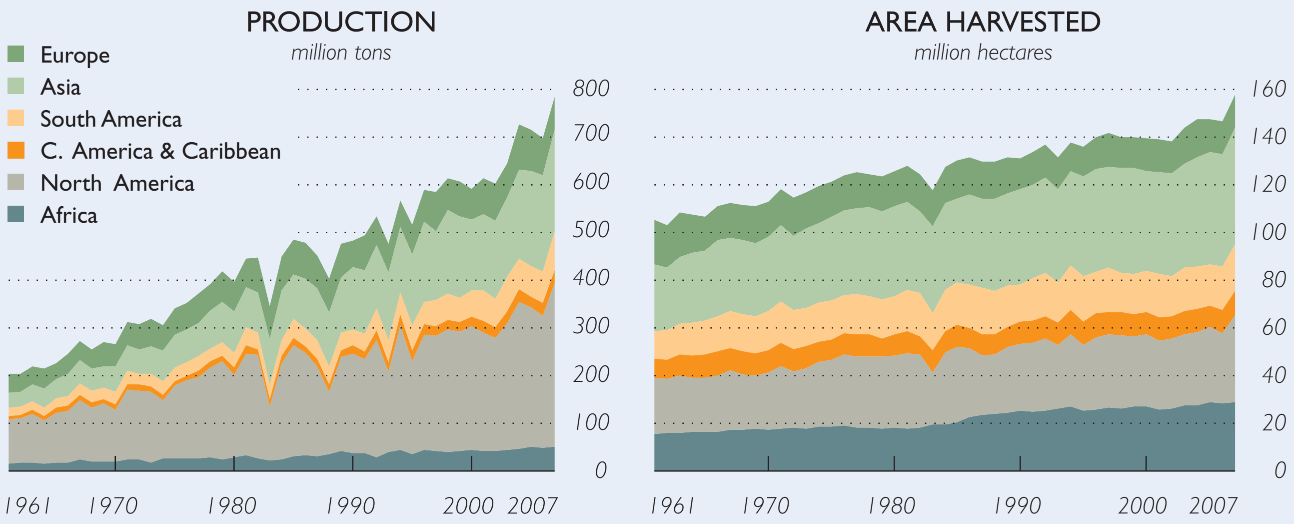
Global production of maize, rice and wheat, 1961- 2007 Figure 2.6 - 3



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Global maize production 1961-2007, by broad geographic region

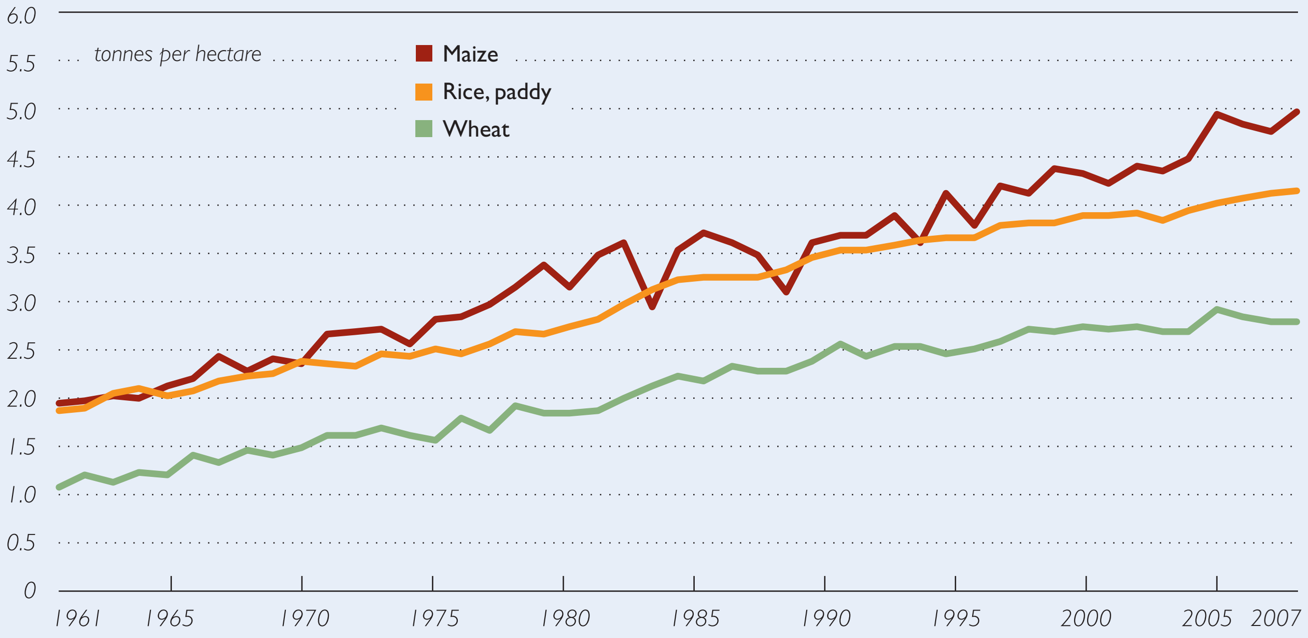
Figure 2.6 - 4



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Global yield development of maize, rice and wheat

Figure 2.6 - 5



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Maize production of major producers, 1961-2007 Table 2.6 - 3

Production *(1000 tons)*	2007	1999-01	1989-91	1979-81	1969-71	1961
USA	332,092	244,260	194,239	192,084	122,649	91,388
China	151,970	116,240	91,891	60,720	32,486	18,027
Brazil	51,590	35,291	23,854	19,265	13,680	9,036
EU27	50,575	57,509	44,987	42,995	30,955	18,966
Mexico	22,500	18,466	13,280	11,607	9,025	6,246
Argentina	21,755	15,215	5,995	9,333	8,717	4,850
India	16,780	12,238	8,892	6,486	6,087	4,312
Indonesia	12,382	9,409	6,394	4,035	2,575	2,283
Canada	10,555	8,168	7,017	5,904	2,487	742
Nigeria	7,800	4,726	5,529	607	1,324	1,107
Others	106,788	83,745	82,790	67,634	52,996	48,047
World +	784,787	605,267	484,867	420,670	282,982	205,005

Source: FAOSTAT accessed Nov. 2008

According to FAO supply utilization accounts, in 2003, some 13 percent of global maize harvest was produced for exports. Global exports increased from 20 million tons in 1961 to 70 million tons by the end of the 1970s remaining stable thereafter. Global exports peaked in 2005 and 2006 with over 90 million tons and declined in 2007 to 80 million tons. The USA has been the world's largest exporter of maize accounting for 55–60 percent of today's global maize trade. Other important exporting countries include Argentina, Brazil, and China. Maize imports are much more evenly distributed across countries and are primarily used as livestock feed for domestic meat production. Maize competes with other feed sources such as other grains, mainly wheat, or cassava. The USDA thus argues that any price changes of maize will have spillover effects to prices of other commodities (USDA, 2008c).

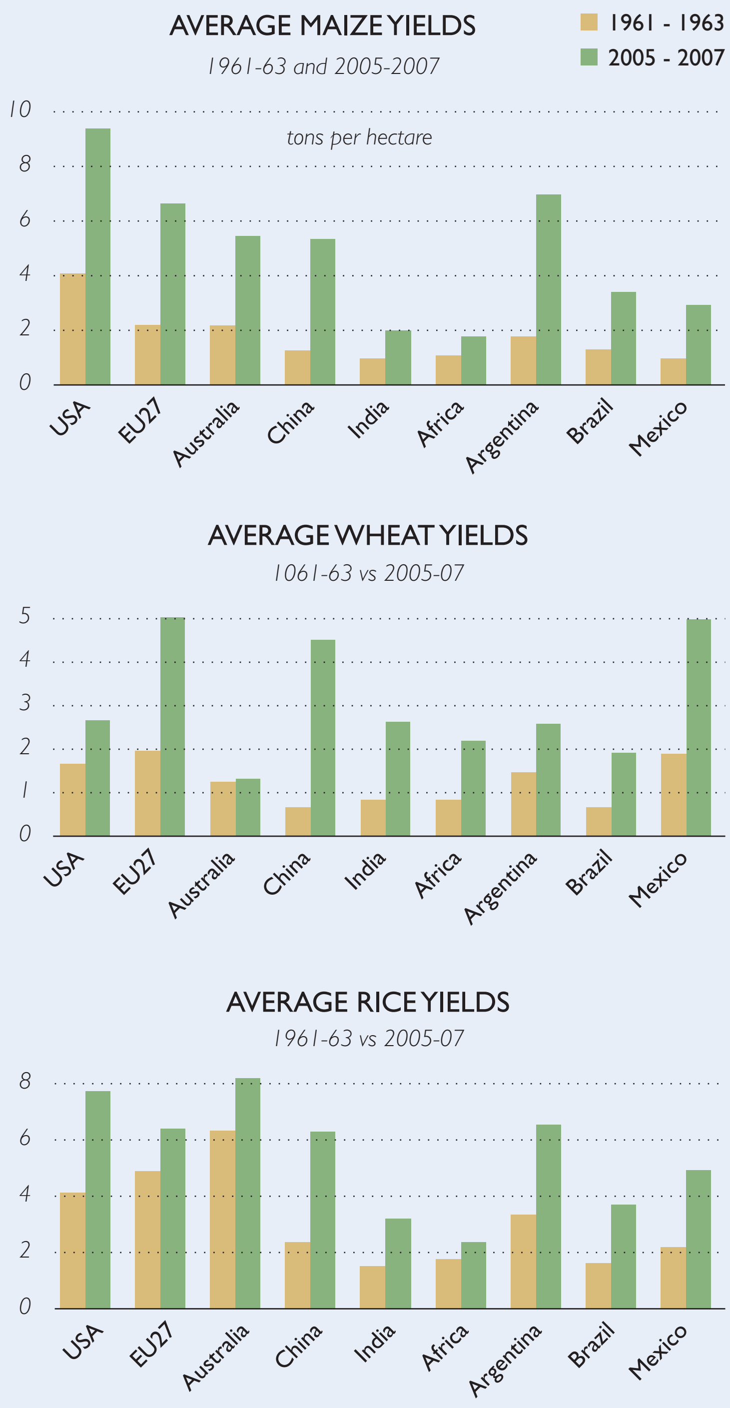
Maize yields

Global maize production increased four-fold over the last 40 years, achieved mainly by a remarkable growth in productivity. Since the beginning of the 1960s, harvested maize areas have increased by 50 percent from 110 million hectares to a current 157 million hectares. Over the same period, global maize production increased from 200 to 800 million tons (Figure 2.6-4). Yield growth was especially pronounced in North America, due mainly to the rapidly spreading use of high-yielding hybrid maize varieties. Global average yield increased from 1.9 tons per hectare in the beginning of the 1960s to approximately 5 tons per hectares in 2007 (Figure 2.6-5). In comparison, from 1960 to 2007 average global yield of rice increased from 1.9 to 4.1 tons, and wheat yield from 1.1 to 2.8 tons.

Highest maize yields have been achieved in the USA; on average more than 9 tons per hectare. Other major producing countries – China, Brazil, and the European Union – achieve, on average, yields of 5.4, 3.7, and 6.3 tons per hectare, respectively. Figure 2.6-6 compares yields of maize, wheat, and rice

Growth of cereal yields of major crops and producers, 1961-2007

Figure 2.6 - 6



AVERAGE MAIZE YIELDS

1961-63 and 2005-2007

AVERAGE WHEAT YIELDS

1061-63 vs 2005-07

AVERAGE RICE YIELDS

1961-63 vs 2005-07

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

achieved in major producing countries/regions in the beginning of the 1960s with average yields during 2005–07. The graph indicates that maize yields have increased substantially in all regions but are still low in Africa and India. While maize is a relatively minor crop in India, it is the most important food staple in Africa, and further yield growth seems possible and is urgently needed.

Genetically modified (GM), insect-resistant maize hybrids represent the culmination of decades of biotechnology research. GM maize is currently widely grown in the USA, Argentina, Brazil - together accounting for 75 million hectares in 2006 - but is also substantially grown in Canada, India, and China.

Maize products

Maize is grown as a source of food, livestock feed, and industrial products[22], including recently, significant amounts of bio-ethanol. Globally, most maize is grown as feed for livestock. Since the 1960s, the share of maize used for livestock feed has remained constant at approximately 65 percent. Nearly 30 percent of harvested maize is used for food with the remainder being seed, waste, and other uses (data for 2003 but the shares have remained stable over the past three decades).

While global food use of maize is under 30 percent, this share is significantly higher in some regions. In Africa, 70 percent of total maize supply, which comprises of 33 million tons production and 10 million tons net-imports, is used for food consumption.

Besides its traditional use for food and feed, maize is increasingly used for producing ethanol, primarily in the United States of America. After 2003, ethanol production has been expanding rapidly and consuming a growing share of the USA maize harvest. While ethanol is still a small fraction of the USA's transport fuel consumption, its significance for the maize market is substantial.

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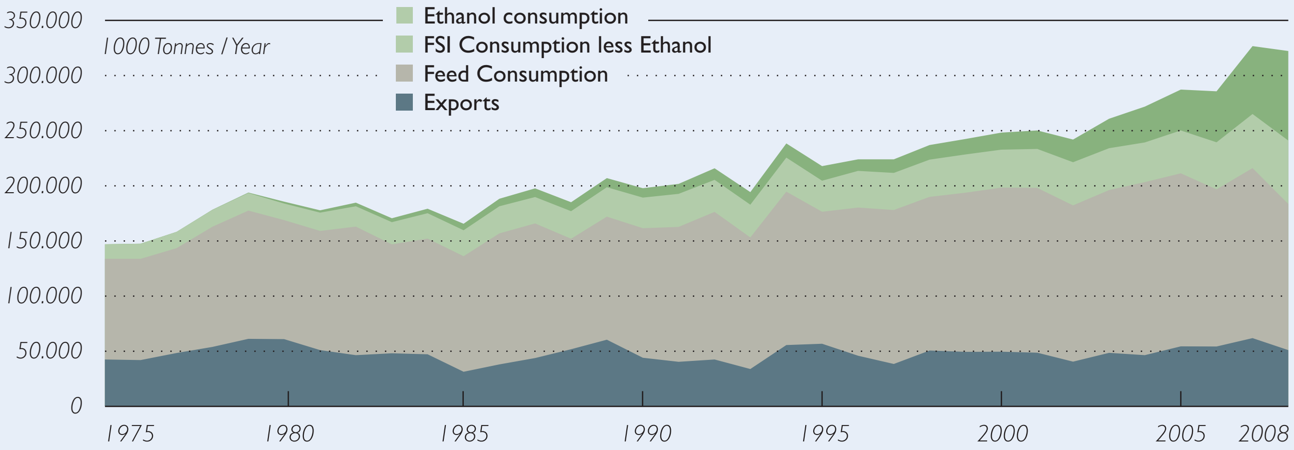
[22] Other industrial products include construction materials, paper goods, textiles, industrial alcohols.

USA maize uses between 1975 and 2008

Figure 2.6 - 7



Source: USDA FAS (2008)

Note: FSI = food, seed and industrial use

Trends in the usage of USA maize production

Increasing levels of ethanol production have raised the USA's demand for maize and changed the structure of the USA maize market (Figure 2.6-7). USA maize production more than doubled between 1975 and 2008 with the strongest increases after 2003. Harvested areas peaked in 2007 amounting to 35 million hectares (Table 2.6-4).

About half of the USA maize crop is used as livestock feed. Export accounts for 20 percent of maize produced. While the share of exports in domestic maize production has decreased over time, the absolute level of maize exports has been constant over the past 25 years fluctuating around 50 million tons. In 2007, about two-thirds of world maize exports originated in the USA.

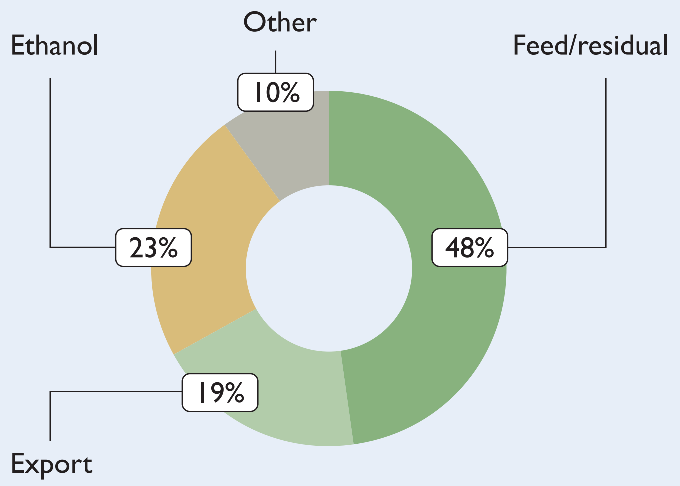
Maize production in the United States of America

Table 2.6 - 4

MAIZE for GRAIN	Planted *mio. ha*	Harvested *mio. ha*	Production *mio. tons*	Yield *ton/ha*	Price per Unit *US$ / bushel*
2008 (estimate)	34.7	31.6	306	9.68	n.a.
2007	37.8	35.0	332	9.50	4.00
2006	31.6	28.5	268	9.38	3.04
2005	33.0	30.3	282	9.30	2.00
2004	32.7	29.7	300	10.08	2.06
2003	31.8	28.7	256	8.94	2.42

Source: USDA Economic Research Service (ERS). http://www.ers.usda.gov/ (accessed November 2008)

Usage of USA maize in 2007–08 Figure 2.6 - 8



Source: http://www.ethanolrfa.org/objects/documents/1898/corn_use_facts.pdf

Since the USA is the world's largest maize exporter, the higher prices resulting from increased domestic demand due to ethanol production have spilled over onto world markets (USDA, 2008c). Maize prices rose from US$ 107 per ton at the beginning of 2005 to US$ 166 per ton at the beginning of 2007, and further rising to US$ 290 per ton by mid 2008. More recently, maize prices have dropped to below US$ 200 per ton.

In 2007–08, 76 million tons of maize were processed in USA ethanol plants, which represents 23 percent of USA maize production (Figure 2.6-8). This figure may be expected to rise to more than 30 percent in future years. The National Corn Growing Association (NCGA) reports strong increases in ethanol production efficiencies from 970 liters ethanol derived from a hectare of maize in 1984 to currently 4210 liters per ha. NCGA projects this to increase to 8400 liters per ha by 2016 (NCGA[23]).

The availability of USA maize for food, feed, or export markets has not yet diminished due to strong increases in production levels. There is however an indirect effect, causing a reduced acreage and lower production of soybeans. Maize and soybeans have similar agronomic requirements and, since soybean cultivation was economically less attractive because of higher maize prices, USA farmers recently converted some land to maize production. Production of soybean in the USA fell from 87 million tons in 2006 to 70 million tons in 2007. In addition, about 15 percent of soybeans were used for biodiesel production. Consequently, soybean imports increased, and stocks diminished.

By-products

While ethanol production consumes the grain's starch, the protein, minerals, fat, and fiber can be concentrated during the ethanol production process providing a highly valued and nutritious livestock feed (see section 2.4). Distillers' grains production (DDGS) from USA ethanol bio-refineries has grown continuously, reaching approximately 14.6 million tons in 2007 (RFA, 2008b). In the 2007–08 marketing year, 22.8 million tons of DDGS were available for global use, nearly a 50 percent increase from the 2006–07 year. It is expected that the 2008–09 marketing year, which began on October 1 2008, will likely experience an additional 50 percent increase in the availability of DDGS, reaching 31.3 million tons (RFA, 2008b).

Cassava

Historical scale, regional distribution and dynamics of cassava production

Cassava (*Manihot esculenta*) is a perennial woody shrub producing an edible root with high starch content. It is also called yucca, manioc, mandioca and tapioca, and grows in tropical and subtropical areas of the world where it is produced mostly by smallholders on marginal or submarginal lands. Cassava became a staple food in many of these places because of its tolerance to drought, less favorable soil conditions, and generally difficult crop environments.

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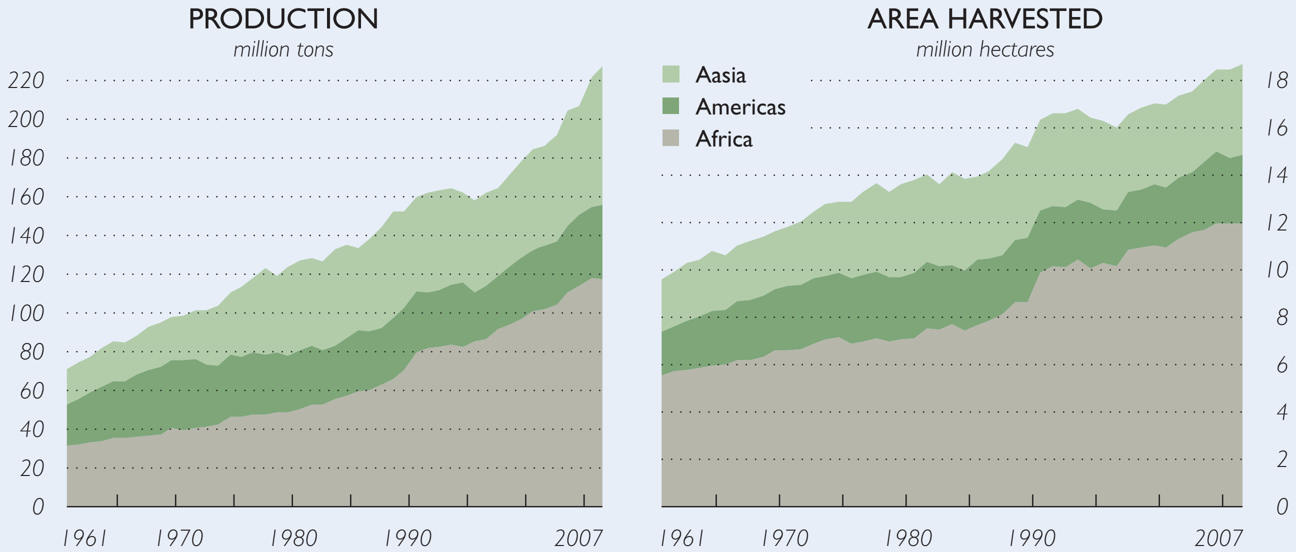
[23] National Corn Growing Association (NCGA) http://www.ncga.com/news/presentations/PDF/022007ProducingFoodFuel.pdf

Cassava production 1961-2007, by broad geographic region

Figure 2.6 - 9



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Cassava production of major producers, 1961 - 2007

Table 2.6 - 5

Production *(1000 tons)*	2007	1999-01	1989-91	1979-81	1969-71	1961
Nigeria	45,750	32,258	20,817	11,500	9,473	7,384
Brazil	27,313	22,259	24,159	24,315	29,922	18,058
Thailand	26,411	17,989	21,557	15,128	3,208	1,726
Indonesia	19,610	16,527	16,300	13,593	10,695	11,190
Congo, Dem. Rep.	15,000	15,965	18,694	12,942	10,232	8,680
Ghana	9,650	8,306	3,913	1,894	1,533	1,050
Viet Nam	8,900	2,432	2,439	3,238	948	965
Angola	8,800	4,319	1,613	1,150	1,597	1,250
India	7,600	6,323	5,070	5,921	4,993	1,969
Mozambique	7,350	5,630	3,994	3,567	2,933	2,600
Others	51,754	46,487	36,800	30,551	22,023	16,390
World +	228,138	178,495	155,355	123,799	97,558	71,262

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008

Cassava is a flexible crop because it grows in diverse environments, from dry to humid climates, acidic to alkaline soils, from sea level to high altitudes, and in nutrient-low soils. Cassava is also highly flexible in its management requirements and has the potential for high-energy production per hectare. The crop has long been used as a food security crop, because cassava roots can be stored in the ground for several months. Thus, harvest may be delayed until market, processing, or other conditions are favorable.

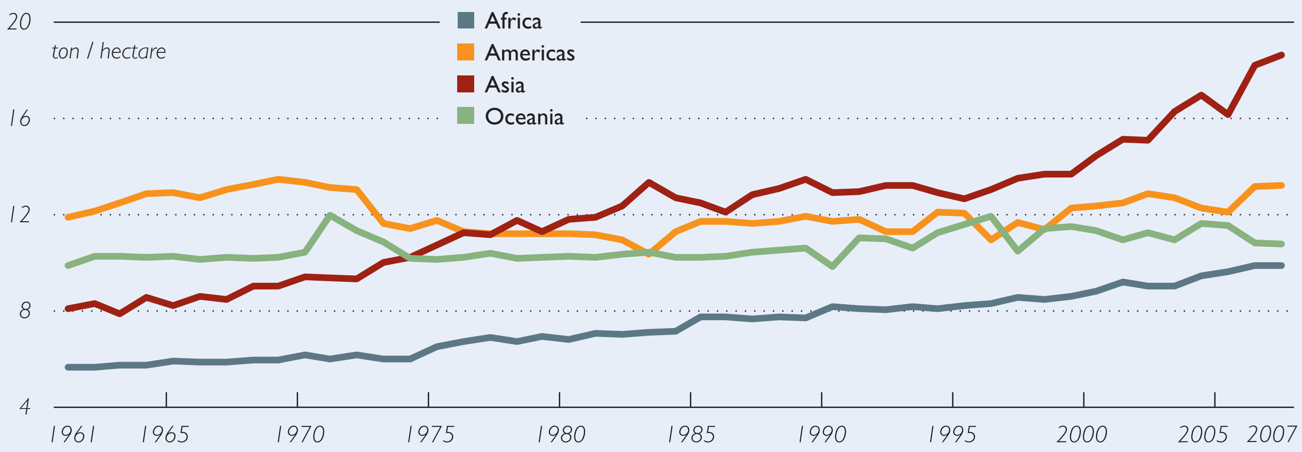
Global cassava production has increased about threefold from the 1960s until 2007, reaching approximately 228 million tons. Since the 1990s, Nigeria has been the world's largest producer, accounting for approximately 20 percent of the global cassava harvest, followed by Brazil, Thailand, and Indonesia. Africa contributes slightly more than half of the global cassava production and Asia about one-third (Figure 2.6-9 and Table 2.6-5). During the same period, area under cassava increased from 10 to 19 million ha.

Agronomic and technical prospects of the Cassava sector for ethanol production

Cassava is the developing world's fourth most important crop and the staple food of nearly one billion people. Cassava yields vary with cultivars, season of planting, soil type and fertility. Yields can be fairly high, 25 to 40 tons per hectare, although national yields are often well below these levels. In 2007, world average yield was 12 tons per hectare, about 60 percent higher than in 1961. Average cassava yields have changed only little in the Americas and Oceania, have substantially increased in Asia, and about doubled in Africa (albeit from a low level) during 1961 to 2007 (Figure 2.6-10).

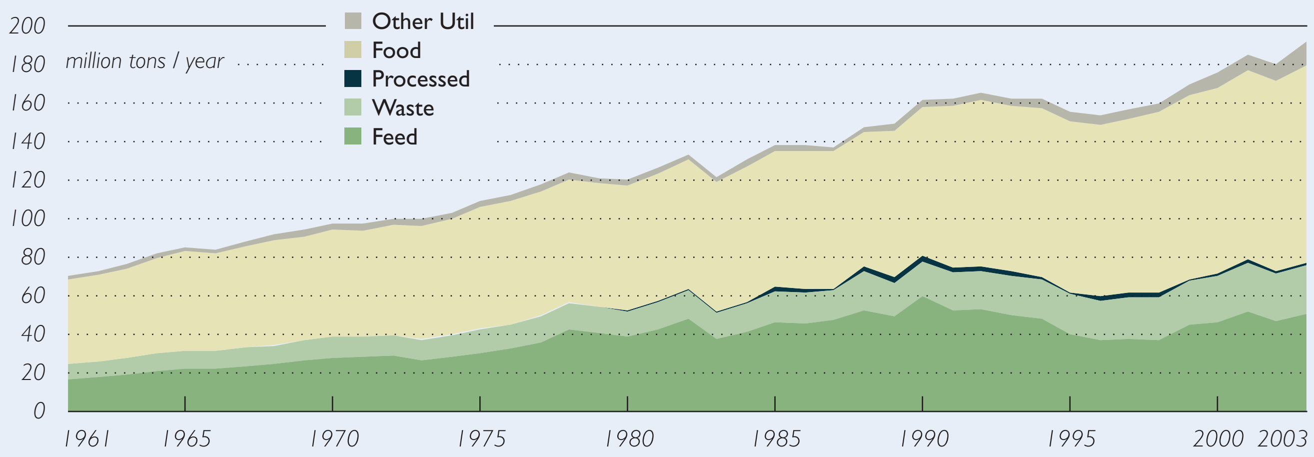
Pests and diseases, together with poor cultural practices, combine to cause yield losses that may be as high as 50 percent in Africa. An example is an aggressive strain of a virus called Cassava Mosaic Disease (CMD), which decimated harvests throughout Africa with disastrous food security consequences.

Cassava yields (tons/hectare) 1961-2007 Figure 2.6 - 10



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Global utilization of cassava, 1961-2003 Figure 2.6 - 11



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

According to FAO (2008), cassava has great potential for increasing yields and expanding production. As a crop of resource-poor farmers and a food security crop, cassava was generally neglected by researchers. Only in the past three decades has an understanding of the crop been greatly advanced. Cassava agronomy research has contributed significantly to the development of improved agricultural practices, such as time and method of planting, intercropping, soil erosion control, and weed control and fertilizing.

Cassava has one of the highest rates of CO_2 fixation and sucrose synthesis for any C3 plant. Researchers from Ohio State University developed transgenic cassava with starch yields up to 2.6 times higher than normal cassava plants by increasing the sink strength for carbohydrate in the crop. Hence, cassava is expected to become an important feedstock when it comes to both CO_2 fixation and carbohydrate production for biofuels.

There are several other reasons why cassava has been strongly recommended for bioethanol production: (i) it can be grown in any season and be a year-round source of ethanol; (ii) high root productivity (though cassava is drought-tolerant, it responds well to the moisture content of soil); (iii) low inputs needed in planting and harvesting (production costs in Thailand are approximately US$ 0.02 per kg); and, (iv) is a high-quantity carbohydrate source. Moreover, the crop yields an amount of woody and lignocellulosic biomass from the shrub that is currently not being used, but which could make a future feedstock for second-generation biofuels or provide energy for processing.

Trends in the usage of Cassava production and trade

The worldwide utilization of cassava for food consumption has decreased from about two-thirds in the 1960s to half of the global harvest in 2003, as more cassava was used for feed and industrial purposes (Figure 2.6-11.).

In Africa and Latin America, cassava is mostly used for human consumption, while in Asia and parts of Latin America it is also used

Cassava trade by major countries, 1961–2006 Table 2.6 - 6

EXPORTS *(1000 tons)*	2006	1999-01	1989-91	1979-81	1969-71	1961
Thailand	19,017	14,603	22,062	13,438	3,206	2,103
Viet Nam	2,602	380	68	0	0	0
Indonesia	413	728	2,858	1,268	939	378
China, Hong Kong SAR	375	212	5	24	1	0
Costa Rica	203	149	49	14	0	0
Paraguay	112	5	0	0	0	0
Others	395	1,071	2,217	3,337	629	645
World	23,116	17,147	27,259	18,081	4,776	3,127
IMPORTS						
China	18,095	4,447	2,582	300	0	0
Indonesia	1,526	473	23	25	0	0
EU27	835	9,046	15,604	13,182	2,877	1,843
Korea, Republic	765	807	1,582	82	0	0
Malaysia	763	427	147	19	9	2
Japan	671	614	1,183	360	246	36
Others	2,100	2,110	5,613	2,716	1,229	825
World	24,754	17,924	26,733	16,683	4,361	2,706

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008

commercially for the production of livestock feed and starch-based products.

In Africa, cassava provides a basic daily source of dietary energy. Roots are processed into a wide variety of granules, pastes, flours, etc., or consumed freshly boiled or raw. In most of the cassava-growing countries in Africa, the leaves are also consumed as a green vegetable, which provides protein and vitamins A and B.

In Southeast Asia and Latin America, cassava has taken on an economic role. Cassava starch is used as a binding agent in the production of paper and textiles, and as a source of monosodium glutamate, an important flavoring agent in Asian cooking.

Trade in fresh cassava is rather limited because of the bulkiness and perishability of the roots. Cassava is traded almost only in processed form as dried chips and pellets, starch, flour, and tapioca. In recent years, about 10 percent of global production was traded: Thailand was the most important exporting country and China has become the leading importer (Table 2.6-6).

Until 1994, Europe was the most important export destination of dried cassava mainly for livestock feed. After that, due to policy changes in Europe resulting in diminishing demand, the portfolio of cassava exports has diversified. Recently there has been some revival in exporting to the European Union.

Cassava is the cheapest known source of starch, and used in more than 300 industrial products. One promising application is fermentation of the starch to produce ethanol, although the FAO cautions that policies encouraging a shift to biofuel production should carefully consider its effects on food production and food security.

The demand for cassava from bioenergy sectors is emerging as a significant driver in the expansion of cassava utilization. A typical production system can produce approximately 280 liters of 96 percent pure ethanol from a ton of cassava with 30 percent starch content.

China is forecast to produce around 1 million tons of ethanol from cassava in 2008. The country is also looking towards agreements with several neighboring countries to supply its ethanol industry with the feedstock both to replace maize, and to allow further expansion of ethanol production. In Thailand, an ethanol plant with a capacity to produce up to 0.5 million liters of ethanol per day came online in 2008. Indonesia is currently gearing up cassava-based ethanol production in preparation for mandatory gasoline blends containing 5 percent ethanol. Construction of ethanol plants is reported to be underway in the Lao Democratic People's Republic, Papua New Guinea, and Fiji, and pilot research for ethanol production is underway in Nigeria, Colombia, and Uganda.

2.6.3
Feedstocks for vegetable oil based biodiesel

Vegetable oils are the principal raw material for biodiesel production. They are obtained from a variety of oil seed crops by crushing the seeds or processing the oil fruit into vegetable oil and oilseed cake or meal. With a worldwide annual production of approximately 134 million tons, vegetable oils constitute a significant product group with vast applications for different food purposes, as well as oleo-chemical and energy purposes. Four crops - palm oil, soybeans, rapeseed and sunflower - accounted for nearly 90 percent of total vegetable oil production in 2008 (Figure 2.6-12a). Approximately 40 percent of the annual vegetable oil production is traded, with palm oil contributing nearly two-thirds of traded oil.

The top five producers in 2008 were Indonesia (23.0 million tons), Malaysia (19.9 million tons), China (15.5 million tons), EU-27 (15.2 million tons), and the United States of America (10.0 million tons) (Figure 2.6-12b). Indonesia (16.8 million tons) and Malaysia (15.3 million tons) are also the largest exporters of vegetable oils, together holding a 60 percent share of global exports (Figure 2.6-13a). The largest importer in 2008 was China (9.0 million tons), followed by EU-27 (7.9 million tons), and India (5.9 million tons) (Figure2.6-13b).

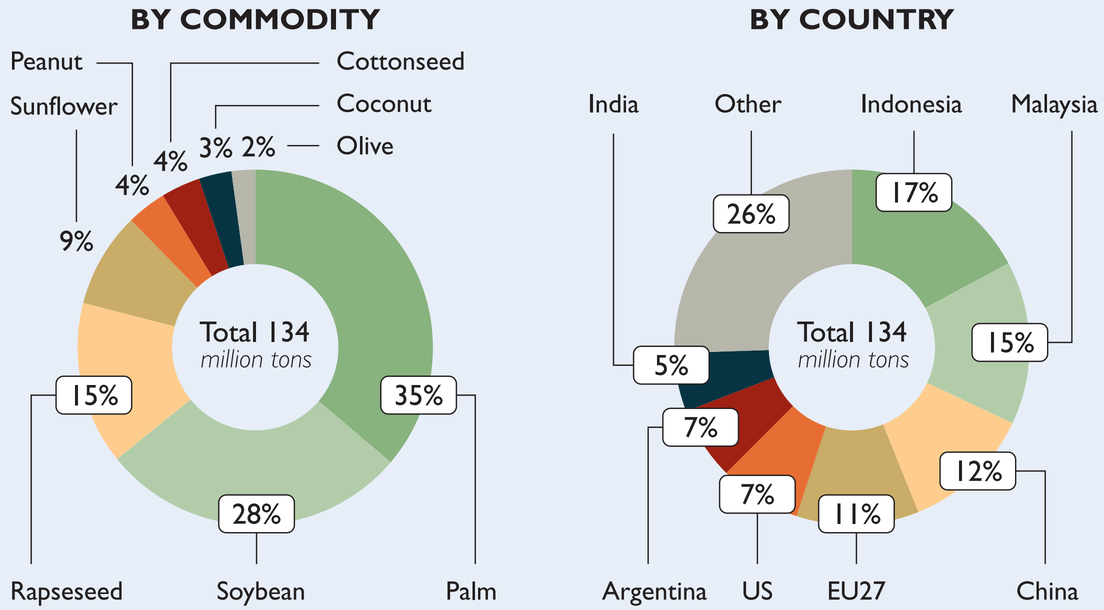
Production of protein meals is dominated by soybeans, contributing, in 2008, two-thirds of a total of 236 million tons produced, and more than 75 percent of 72 million tons of protein meals traded. Argentina (28.6 million tons) ranks first among exporters, and EU-27 (27.7 million tons) is by far the largest importer.

The major vegetable oils – from soybean, oil palm, rapeseed and sunflower – are mutually substitutable in most of the main uses (Schmidt & Weidema, 2007). As a result, the prices of different vegetable oils are closely interlinked. An increase in the demand for any particular vegetable oil is likely to increase prices for all of them.

While utilization of vegetable oils is still primarily for food use, the soaring biodiesel industry is demanding significant amounts of

Global production of major vegetable oils, 2008

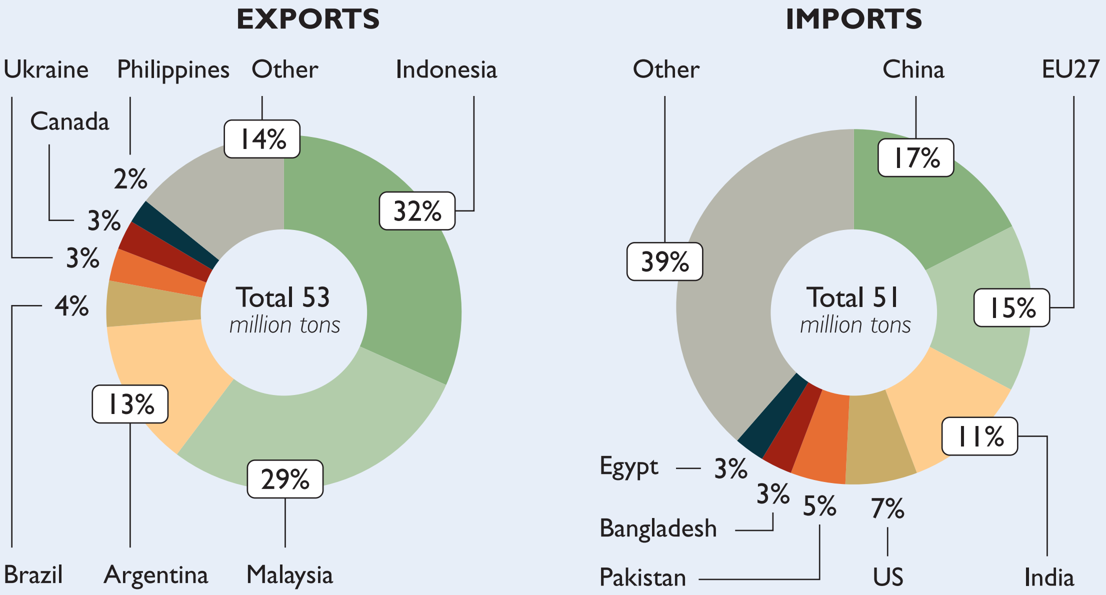
Figure 2.6 - 12



Source: USDA FAS, Oilseed: World Market and Trade, 2008.

Global trade of major vegetable oils, 2008

Figure 2.6 - 13



Source: USDA FAS, Oilseed: World Market and Trade, 2008.

oil; an estimated 10 percent of global vegetable oil production to produce 14.7 billion liters of biodiesel in 2008. Approximately 60 percent of this production took place in Europe, mostly within the EU. Germany is the largest biodiesel producer globally.

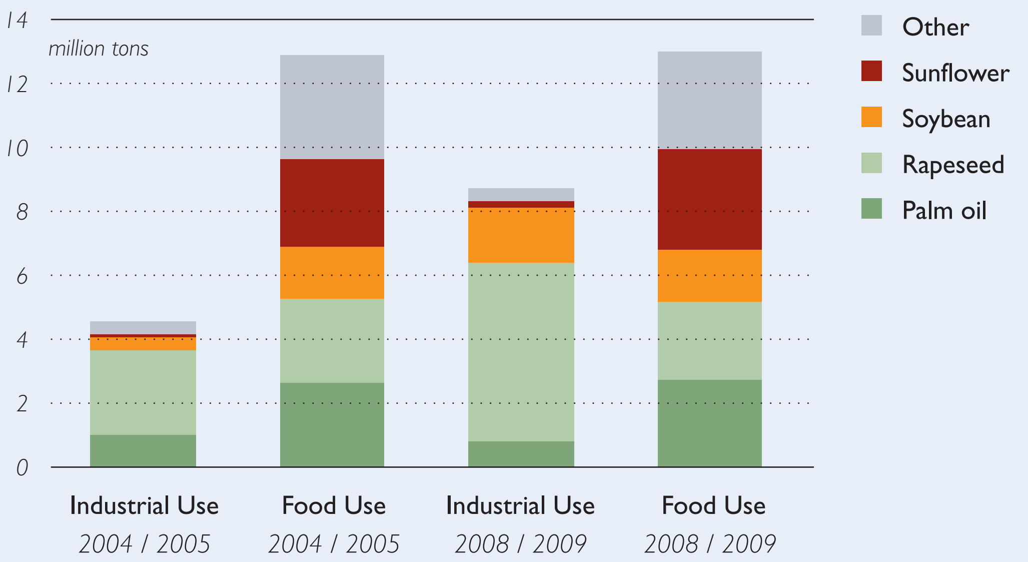
Use of vegetable oils for biodiesel

The growing biodiesel industry had a significant impact on the structure of the EU oilseed markets in terms of production and trade patterns of oilseeds, vegetable oils and its by-products. The rapidly expanding biodiesel production implies increased use of vegetable oils for industrial purposes[24]. Approximately 95 percent of the current growth in demand for vegetable oils within the EU is due to biofuels. While domestic vegetable oil consumption for food use remained constant over the past few years, amounting to approximately 13 million tons, vegetable oil consumption for industrial use nearly doubled between 2004–05 and 2008–09 (Figure 2.6-14). The main driver was increased biodiesel production from rapeseed oil, the major biodiesel feedstock, followed by soybean oil (Figure 2.6-16).

According to DG AGRI[25], oilseed use for fuel is estimated at 9.2 million tons in 2007–2008, one million tons more than in the previous year, and double the amount used in 2004–2005. Thus, about 20 percent of total oilseed supply[26] was used for transport fuels. Apart from converting vegetable oils (almost exclusively rapeseed oil) into biodiesel, a considerable amount of vegetable oils (at least 0.6 Mtoe in 2006) is used directly as fuel in transport (mainly rapeseed oil) and in stationary plants (mainly palm oil).

Total EU oilseed supply in 2007–08 was 43 million tons (USDA FAS, 2008b). The main contributors were domestic rapeseed and sunflower production (43 percent and 11 percent of total supply) and imported soybeans (33 percent) (Figure 2.6-15, left). About half of the

Vegetable oil industrial and food use in EU-27 in 2004/05 and 2008/09 Figure 2.6-14



Source: USDA FAS, 2008, Oilseed: World Market and Trade

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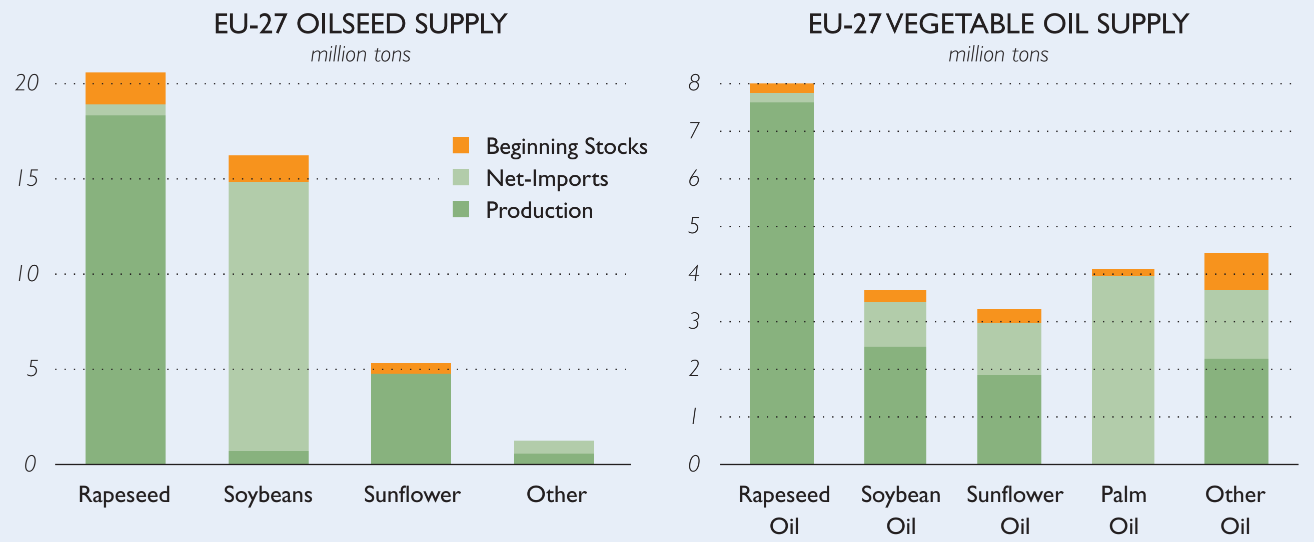
[24] See http://www.fas.usda.gov/oilseeds/circular/2005/05-10/octcov.pdf

[25] DG AGRI 2008 http://ec.europa.eu/agriculture/bioenergy/index_en.htm

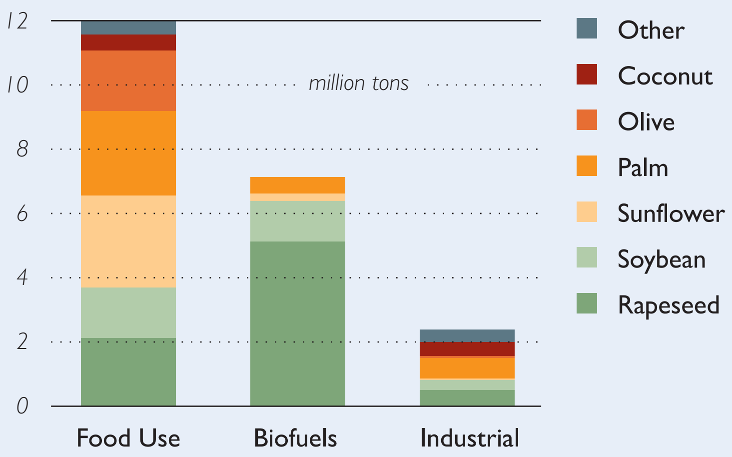
[26] DG AGRI reports a total oilseed supply of 49.7 million tons for 2007

Origin of EU-27 oilseeds and vegetable oil supply in 2007/08 Figure 2.6 - 15



Source: USDA FAS, 2008.

EU-27 vegetable oil use in 2007/08 Figure 2.6 - 16

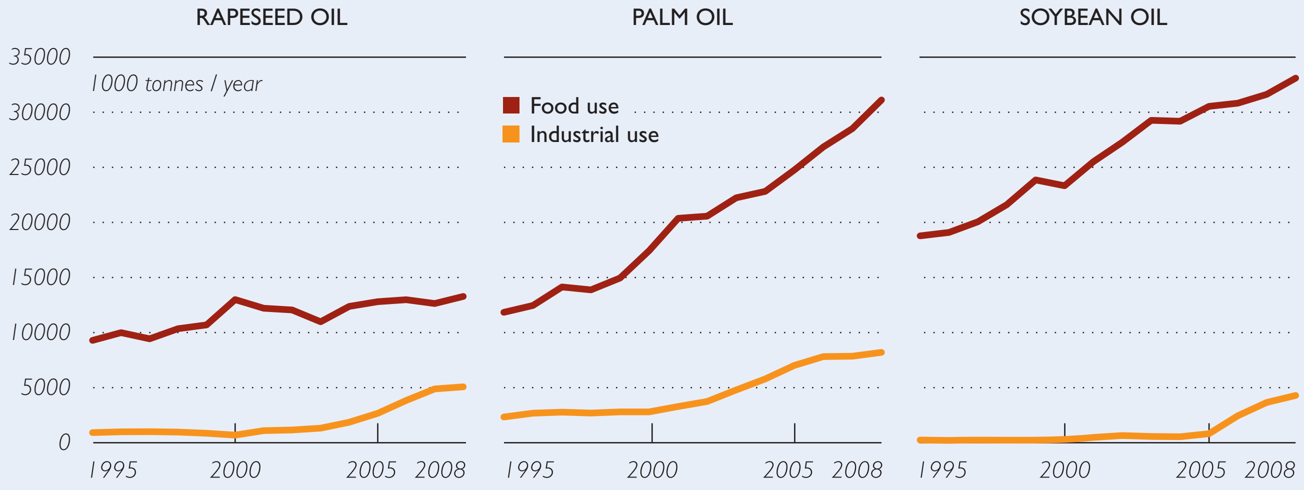


Source: USDA FAS, 2008.

total EU oilseed supply was from domestic production with planted areas of 6 million hectares of rapeseed and 4 million hectares of sunflower. Of this, arable land with energy crops was 4 million hectares in 2007, i.e. some 4 percent of the EU's total of 110 million hectares[27] of arable land. The majority of energy crops were rapeseed planted on 2.9 million hectares. EU rapeseed imports increased sharply over the last three years and are estimated at 1.8 million tons for 2008–09. Major exporters to EU-27 are Ukraine and Russia. Ukraine rapeseed production accelerated after 2005 and reached 2.7 million tons in 2008–09 (up from 1.2 million tons in 2007–08 and 0.5 million tons in 2006–07).

The vast majority of total oilseed supply was crushed (37.2 million tons) into vegetable oils and meals[28]. Oilseed crushing capacity expanded considerably over recent years in response to the growing vegetable oil demand from the biofuels industry. Oil millers have increased crushing capacity for rapeseed partly at the expense of soybeans.

Worldwide use of most important vegetable oils Figure 2.6 - 17



Source: USDA FAS, 2008. Oilseed: World Market and Trade.

Besides increased vegetable oil production, the increasing absorption of domestically produced rapeseed oil for biodiesel, and the subsequent gap in EU vegetable oil supplies for food products, has also led to increased imports of vegetable oils. Since 2005, the EU has moved from being a small net-exporter of rapeseed oil to a major net-importer[29].

Total EU vegetable oil supply in 2007–08 was 23.4 million tons. Of this, nearly two-thirds were derived from domestic mills and one-third from imports (Figure 2.6-15, right). More than half of the EU domestic rapeseed oil production is located in Germany and France, major consumers of biodiesel. Most of imported vegetable oils was palm oil and palm kernel oil (from Malaysia and Indonesia), but also sunflower oil, soybean oil, and coconut oil.

Vegetable oil in the EU is primarily used for food, the share for industrial use, especially biodiesel, has increased significantly over recent years. By 2007–08, from the total vegetable oil use in the EU of almost 22 million tons, 55 percent was for food use, 33 percent for biodiesel, 11 percent for other industrial uses, and 2 percent was waste. Figure 2.6-16 highlights the distribution of the different vegetable oils for food use, biofuels, and other industrial uses.

Globally, industrial use of total vegetable oil consumption has increased substantially from approximately 10 percent at the beginning of the 2000s to currently approaching 20 percent. Six percent of global vegetable oil is now being used by the EU for the production of biodiesel.

Figure 2.6-17 compares the trends in food use versus industrial uses for the three major global vegetable oils. In all three cases the strong impact of biodiesel production on increasing the industrial uses of vegetable oil after 2003 is clearly visible.

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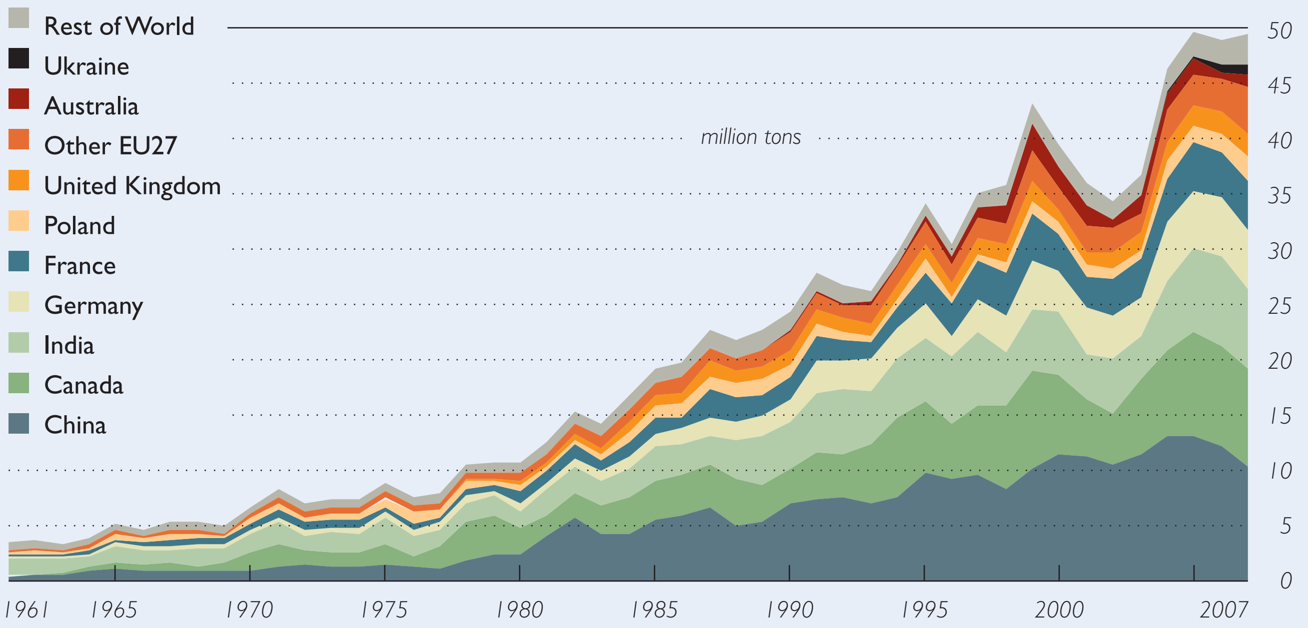
27 FAOSTAT reports for 2005 110 million hectare arable land for the European Union. Eurostat reports 100 million ha for 2005 for EU-27 (Eurostat (2008): Agricultural statistics: Main results 2006/2007, available at:http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ED-08-001/EN/KS-ED-08-001-EN.PDF)

28 The remaining use of oilseeds was: Exports (0.738 mio. tons), direct food use (0.997 mio.tons) and Feed, Seed, Waste (2.783 mio. tons).

29 Traditional suppliers, Canada and Australia have not been able to keep pace with surging EU demand, particularly in 2007 with the drought in Australia.

Global rapeseed production, 1961 to 2007

Figure 2.6 - 18



Source: FAOSTAT accessed Nov. 2008

Major rapeseed producers, 1961 – 2007

Table 2.6 - 7

Production *(1000 tons)*	2007	1999-01	1989-91	1979-81	1969-71	1961
EU27	18,305	12,407	8,775	3,086	1,853	905
China	10,375	10,948	6,610	2,952	1,028	388
Canada	8,864	7,007	3,567	2,581	1,517	254
India	7,097	5,213	4,577	1,864	1,629	1,347
Australia	1,065	1,986	116	24	31	0
Ukraine	1,060	138	0	0	0	0
USA	660	813	67	0	0	0
Russian Federation	600	132	0	0	0	0
Pakistan	384	308	237	249	249	214
Bangladesh	240	247	217	225	132	99
Others	829	342	824	305	211	388
World +	49,479	39,540	24,990	11,287	6,648	3,596

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Rapeseed

Historical scale, regional distribution and dynamics of rapeseed production

Rape (*Brassica napus*), and, in the case of one particular group of cultivars, canola, is a bright yellow flowering herbaceous plant. It is one of the oldest cultivated plants. From antiquity right down until the nineteenth century, rapeseed oil was used mainly for lighting and as a lubricant.

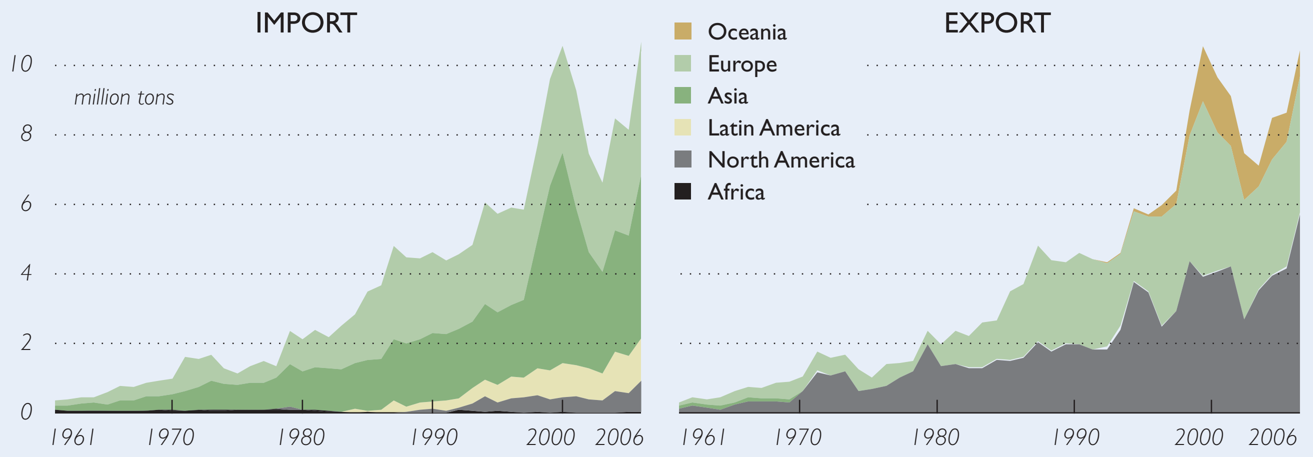
Until the 1970s, rapeseed oil was not used for food consumption as it contained too much erucic acid, which can be mildly toxic in high doses. Erucic acid, as well as glucosinolates contained in the rapeseed meal (the by-product of rapeseed oil production), made it unfit for livestock feed. Once plant breeders were able to eliminate these two undesirable substances, rapeseed started to be grown, not only as a raw material for industrial oils, lubricants, and biodiesel, but also for use as a source of cooking oil and margarine production. In Canada, the crop was renamed as "canola" (Canadian oil) to differentiate it from non-edible rapeseed.

With new rapeseed varieties available, production increased significantly after 1980, from a worldwide production of 10 million tons annually to 50 million tons currently. Area harvested increased from 5 million hectares in 1961 to 30 million hectares in 2007 (Figure 2.6-18). Leading producers include China, India, Canada, and the European Union. Mustard/rapeseed is the preferred cooking oil in India and has been in use since 1500BC. In the 1960s India was by far the largest producer (Table 2.6-7).

Rapeseed trade

Figure 2.6-19 and Table 2.6-8 depict the evolution of rapeseed trade since the 1960s. After 1980, when rapeseed production significantly increased, approximately 20 percent of global production has been traded. In the late 1980s, the European Union was the largest exporter followed by Canada. Since the beginning of the 1990s, Canada emerged as the largest rapeseed exporter and currently accounts for 50 percent of global exports. Canada's production is largely for the world market with 50–60 percent of production being exported. Recently (after 2000), Australia became another important rapeseed exporter.

Global rapeseed trade 1961-2005, by broad geographic region Figure 2.6 - 19



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Exports are destined primarily for Asia. In 2007, 60 percent of global rapeseed exports went to Japan, China, and Pakistan. Japan has been a stable importer, crushing rapeseed for the production of rapeseed oil and meal for livestock feed. Although China produces large amounts of domestic rapeseed, in some years it has imported significant amounts (e.g. in 2000 China was the largest rapeseed importer). After 2000, Germany, Belgium, and Mexico also became large rapeseed importers (Figure 2.6-19 and Table 2.6-8). The production of rapeseed in the European Union is still 'conventional' as Europe prohibits imports of GM rapeseed and GM rapeseed oil for food use.

Rapeseed is crushed to produce vegetable oil and protein-rich cake or meal, the latter being used as a valuable livestock feed. The FAO reports that over the last three decades between 80 to over 90 percent of global rapeseed as being crushed, with the remainder fed directly to livestock as a forage crop, for seed production, or being lost as waste. Of the rapeseed by-products, some two-thirds of the value (in monetary terms) is in the vegetable oil and about one-third in the cake[30].

Rapeseed yields

Today half of the harvested rapeseed area is in Asia, mainly China and India. Yields vary across countries but have been increasing in all regions. Average yields in Asia are approximately 1.3 tons seed per hectare. This is only

Rapeseed trade by major exporters and importers, 1961–2006 Table 2.6 - 8

EXPORTS *(1000 tons)*	2006	1999-01	1989-91	1979-81	1969-71	1961
Canada	5,548	3,874	1,905	1,583	698	123
EU27	3,373	4,050	2,474	637	468	89
Australia	764	1,535	0	0	1	0
Ukraine	471	59	0	0	0	0
USA	167	201	20	0	0	0
Russian Federation	63	37	0	0	0	0
Others	80	43	64	24	66	98
World +	10,465	9,799	4,463	2,245	1,233	310
IMPORTS						
EU27	3,787	3,179	2,245	976	631	146
Japan	2,274	2,181	1,847	1,116	340	24
Mexico	1,207	919	241	9	4	0
Pakistan	964	289	0	0	10	0
China	738	2,430	6	0	20	0
USA	734	239	61	0	0	1
Others	1,082	622	109	196	185	177
World +	10,787	9,859	4,509	2,298	1,191	349

Source: FAOSTAT, online database at http://www.fao.org, accessed January 2009.

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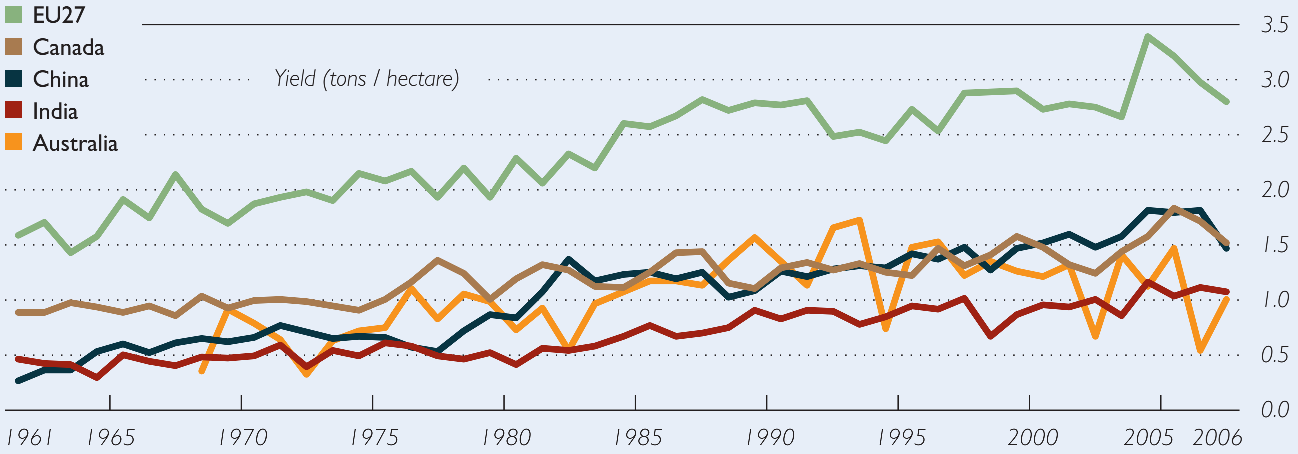
[30] FAO divides rapeseeds value share (in monetary terms) into 72 percent for the oil and 28 percent for the cake.

Rapeseed yields of major producers, 1961-2007

Figure 2.6 - 20



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

half the yield level achieved in Europe, where an average of 2.5 tons per hectare is produced. Canada and Australia produce rapeseed with less agricultural inputs compared to Europe. Average yields are therefore lower at 1.5 and 1.0 ton per hectare, respectively. Figure 2.6-20 shows yields of major rapeseed producers. It also indicates that variability of yields has been particularly high in Australia where recent drought and climatic extremes have also affected yields of other major crops.

Although many field trials with genetically modified (GM) rapeseed have been conducted in Europe, GM rapeseed is not being grown there commercially. GM rapeseed has been grown in Canada since 1996 and in 2005 was grown on 4.6 million hectares accounting for approximately 75 percent of Canada's rapeseed crop. GM rapeseed is grown to a lesser extent in the USA and in some states in Australia. All of the GM rapeseed grown throughout the world is herbicide resistant, which enables a more efficient and effective approach to weed control. Currently genetically modified rapeseed cultivars with increased vitamin A are being developed.

Rapeseed oil

Rapeseed oil is produced[31] by pressing the oil from the seeds and refining it to remove free fatty acids and other impurities. Rapeseed seed contains 40–44 percent oil. With global production of almost 20 million tons in 2008, rapeseed oil ranked third in global production among all vegetable oils, being exceeded only by palm and palm kernel oils (approximately 48 million tons in 2008) and soybean oil (approximately 37 million tons in 2008).

Rapeseed oil production increased six-fold between 1976 and 2006 with Asia (mainly China and India), Europe (especially Germany and France), and to a lesser extent North America (mainly Canada) being the largest producers (Figure 2.6-21 and Table 2.6-9). Major rapeseed producers also have the crush capacity in country and can produce rapeseed oil. The exception is Japan, which imports all rapeseed for its rapeseed oil production.

Rapeseed oil is traded extensively. Nearly 20 percent of global rapeseed oil production is produced for exports (approximately 11 percent when excluding EU-27 internal trade). Rapeseed oil is traded extensively among

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[31] Rapeseed is normally processed in two steps: 1) Physical pressing of the rapeseed and 2) Subsequent hexane extraction of the remaining oil in the press-cake. Some smaller plants are only press-plants and do not apply the second step of hexane extraction. This results in high oil content in the cake, which makes this process economically not viable because of the high price differential between rapeseed oil and rapeseed meal or cake.

Rapeseed-oil production of major producers, 1961 – 2007

Table 2.6 - 9

Production *(1000 tons)*	2007	1999-01	1989-91	1979-81	1969-71	1961
EU27	6,027	4,323	3,123	1,347	747	319
China	4,348	3,517	1,678	828	298	105
India	2,338	1,616	1,475	566	498	399
Canada	1,304	1,214	600	388	75	9
Japan	951	901	748	444	148	118
USA	500	300	35	0	0	0
Mexico	490	345	89	4	3	1
Pakistan	222	209	75	75	57	26
Australia	168	151	45	10	7	0
Bangladesh	120	156	67	69	64	56
Others	359	207	301	149	88	66
World +	16,827	12,938	8,237	3,880	1,987	1,099

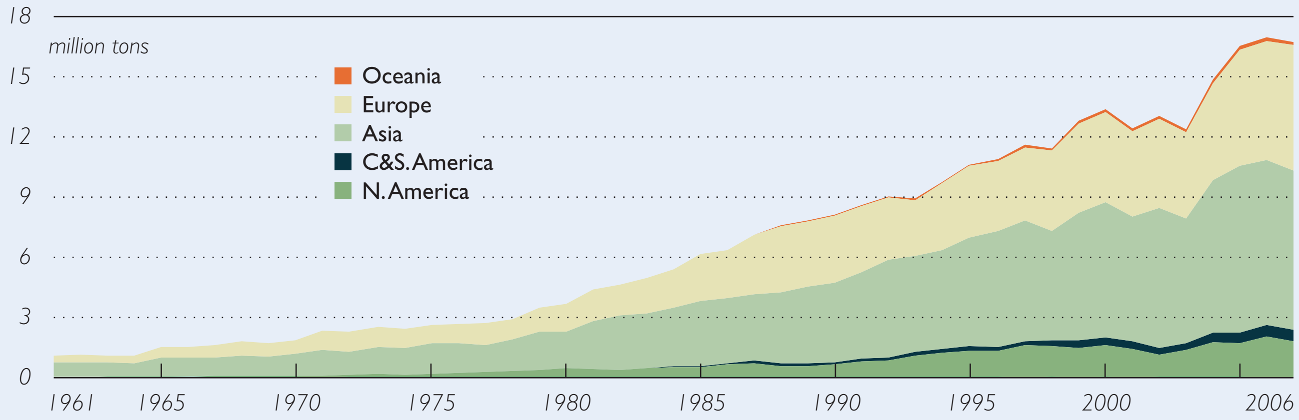
Source: FAOSTAT, accessed November 2008

European countries. Canada dominates global rapeseed oil trade (approximately two-thirds of global trade excluding EU-27 internal trade) with exports to the Asian market.

Rapeseed oil is widely used as cooking and salad oils, and for making margarine. Of all major edible vegetable oils, it has the lowest saturated fat content, making it a versatile cooking ingredient with proven health benefits. It is rich in omega 6 and omega 3, essential fatty acids that cannot be synthesized by the body and must be provided by diet.

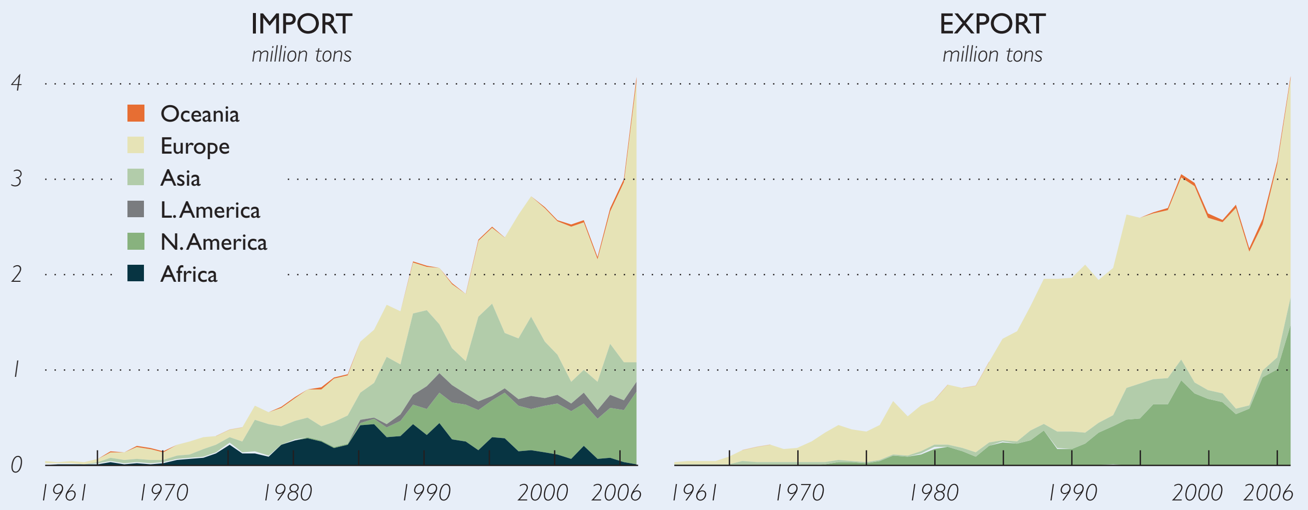
Global rapeseed-oil production 1961-2007

Figure 2.6 - 21



Source: FAOSTAT, accessed November 2008

Global rapeseed-oil trade 1961-2006 Figure 2.6 - 22



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

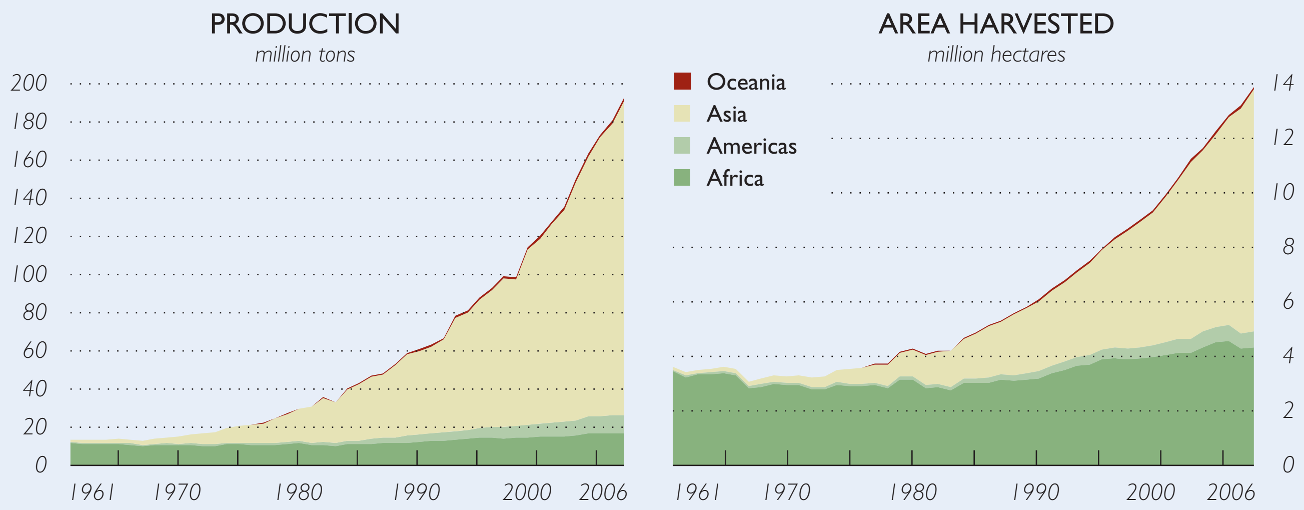
Other uses of rapeseed oil are for industrial products including lubricants and oleo-chemical uses. As pointed out earlier, more recently, rapeseed oil has been used in large quantities to produce biodiesel in the European Union. Unlike palm oil, with a tripling of global food use, and soybean oil use growing 2.5 times during 1985–2008, the worldwide use of rapeseed oil for food has been stable over the past decade (see Figure 2 .6-17).

By-products

The development of European biodiesel production not only impacts plantings, crop production, and trade of oilseeds and vegetable oils, but also the market for livestock feed. Processing of rapeseed for oil production provides rapeseed meal and cake as a by-product, which is a high-protein livestock feed. For every ton of rapeseed processed 0.6 tons of rapeseed cake is produced. Rapeseed oil cake is the most commonly preferred livestock feed because it contains 16–24 percent protein. Rapeseed meal contains approximately 40 percent protein, which nutritionally rates among the best plant proteins. The feed is mostly used for cattle, but also for pigs and poultry. For livestock diets, it has better amino acid balance than soybean meal. The meal obtained from the rapeseed variety produced in the EU has a very low content of glucosinolates which are responsible for metabolism disruption in cattle and pigs. As a result, methane emissions from the livestock is reduced. Over the past few years, rapeseed meal has increasingly replaced soybean meals in cattle and swine feed rations in Germany and France.

The economic viability of the biofuel industry will depend on the ability of the industry to derive value from both the biofuel it produces and the by-products that are generated during the process. Moreover, the environmental performance of biofuel production chains greatly improves if by-products are used. Credits for by-products are also an important element in the estimation of greenhouse gas reductions of the different biofuel production chains compared to fossil fuel use (e.g. CONCAWE, 2006; EC, 2008).

Oil palm-fruit production 1961-2007, by broad geographic region Figure 2.6 - 23



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Oil palm

Historical scale, regional distribution and dynamics of palm oil production

Oil Palm (*Elaeis*) originated in West Africa, where it is used extensively as cooking oil. Plantations were originally interplanted with other annual and perennial crops. Until the 1970s, Africa was the largest producer of oil palm, primarily in Nigeria and the Democratic Republic of Congo. Over the last three decades, palm oil cultivation has been expanding more rapidly than almost any other agricultural commodity. In the 1970s, major monoculture plantation programs started in Malaysia and Indonesia.

The area of oil palm plantations more than tripled from 4 million hectares in the beginning of the 1980s to 14 million hectares currently (Figure 2.6-23). The vast majority of this increase was concentrated in Malaysia (4.3 million hectares[32]) and Indonesia (6.1 million hectares[33]), together representing more than 80 percent of the total worldwide production of more than 190 million tons (Figure 2.6-24). The palm fruit is the source of both palm oil (extracted from the flesh) and palm kernel oil (extracted from the seeds), of which, 43 and 5 million tons of oil, respectively, were produced globally in 2008–09. Oil palm is the largest source of vegetable oil accounting for one-third of global vegetable oil production.

Oil palm is the most productive oil crop, with the highest yield of oil per unit area. Modern high-yielding varieties developed by breeding programs, under ideal climatic conditions and good management, are capable of producing in excess of 20 tons of bunches per hectare per year, with palm oil in bunch content of 25 percent. This is equivalent to a yield of 5 tons of oil per hectare per year (excluding the palm kernel oil), which far outperforms any other source of edible oil (FAO, 2008a).

However, such high yields can only be achieved when climatic conditions are optimal. Over the last decade, average annual

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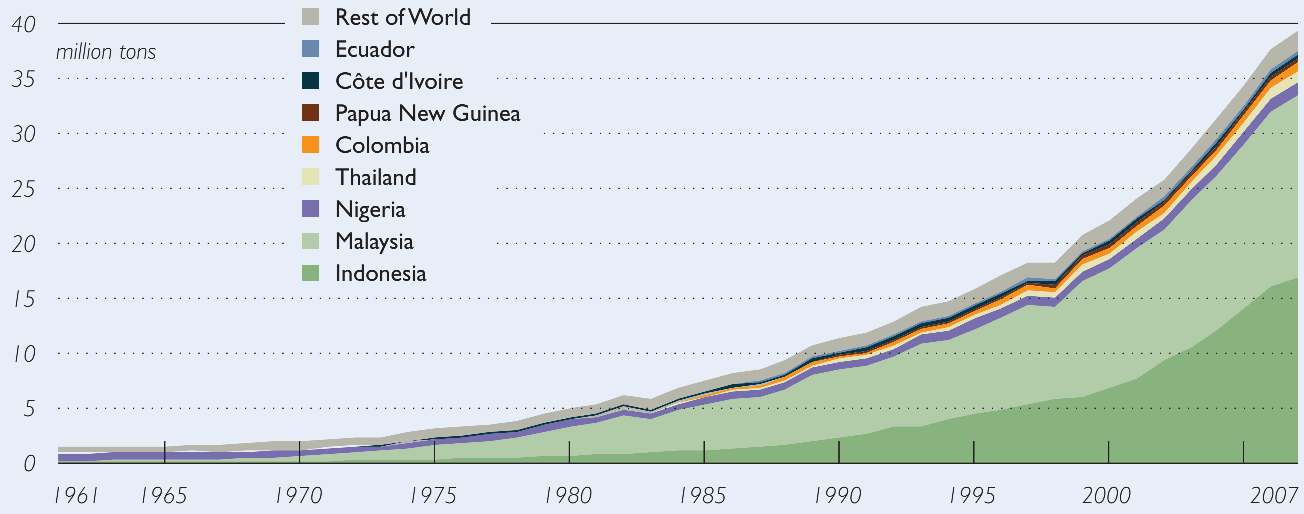
[32] Malaysian Palm Oil Board. www.mpob.gov.my

[33] For Indonesia data on actual area planted to oil palm is not easily obtained (USDA, 2007). Figures of harvested area range between 4.6 million hectares in 2007 (FAOSTAT) and 6.1 million hectares for 2005 (Fitzherbert, 2008).

Evolution and geographic distribution of palm oil production Figure 2.6 - 24



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

yields in Malaysia and Indonesia were between 17–20 tons of palm fruit per hectare, equivalent to 4–5 tons of palm oil per hectare. Due to erratic rainfall in Central and West Africa, and lack of adequate management, yields are substantially lower in Africa, amounting to less than 3 tons of palm fruit per hectare. The need for costly inputs of imported fertilizers, pesticides, and harvesting machinery can also limit the yield.

Trade of palm oil

Over 70 percent of global palm oil production, or 31 million tons, is exported around the world, with over 90 percent originating from Malaysia and Indonesia. Malaysia exports 80–90 percent of its palm oil and Indonesia 70 percent, (a figure that sharply increased from around 50 percent in the 1990s). Current main importing regions are China (5.7 million tons), India (4.9 million tons), the European Union (3.9 million tons), and Pakistan (2.5 million tons). The strongest import growth occurred in China, where palm oil imports have increased five-fold since 2000 (Figure 2.6-25).

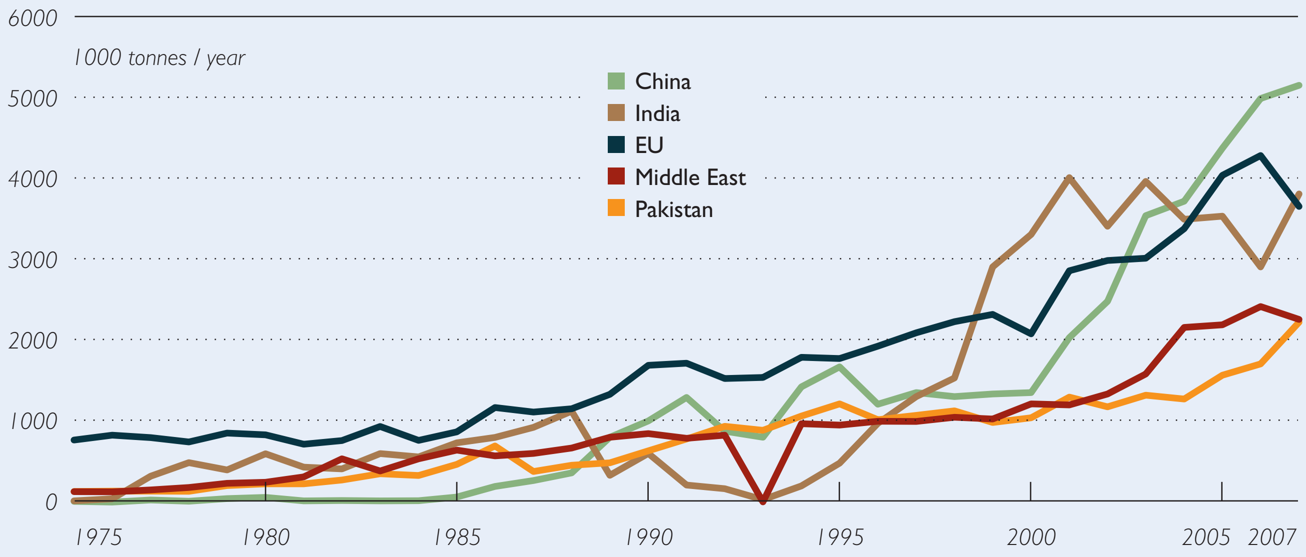
Palm oil use

Palm oil's semi-solid properties make it a favorite ingredient among food processors. The oil can be incorporated into a wide variety of food products including cooking oils and margarines. Due to its stability, palm oil is a good frying oil. Industrial use of palm oil includes liquid detergents, soaps, waxes, and fuel oil, e.g. for biodiesel production.

The global use of palm oil for food has doubled over the past 8 years. Since 2003, industrial applications have also grown, which may be partly related to increased biodiesel production, and other oleo-chemical applications. Currently, approximately 20 percent of palm oil is used for industrial purposes (Figure 2.6-17). The use of palm oil for biodiesel production has been rather small amounting to only 1 percent of total biodiesel production (Kleffmann, 2007). However, Indonesia and Malaysia have announced ambitious plans for biodiesel production.

Major importers of palm oil, 1975 - 2007

Figure 2.6 - 25



Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Sustainability of production

The rapid expansion of palm oil plantations in tropical countries since the mid 1980s has triggered serious concerns regarding tropical deforestation, peat land destruction, loss of habitats for endangered species, and adverse social impacts for indigenous people. In a response to these mounting concerns, the Roundtable on Sustainable Palm Oil (RSPO[34]) was established in 2004 with a principle objective "to promote the growth and use of sustainable palm oil through co-operation within the supply chain and open dialogue between its stakeholders". Towards this end, the RSPO is promoting the development of certification schemes for sustainable oil palm production.

Tropical deforestation and biodiversity

Oil palm cultivation requires the tropical, high-rainfall, low-lying areas of Asia, Africa, or South America. These zones are naturally occupied by tropical rainforest, the most biologically diverse ecosystem (Corley & Tinker, 2003). Traditionally, oil palm in Africa has been established in agro-forestry systems that were harvested over several decades. In Southeast Asia, oilpalm is grown as monoculture plantations, the development of which has resulted in the conversion of large areas of forests with high conservation value and threatened the rich biodiversity in these ecosystems. Malaysia and Indonesia hold more than 80 percent of Southeast Asia's remaining primary forests (mainly in Indonesia). Some of the highest global rates of deforestation have been observed in these countries and oil palm production has contributed to this to some extent (Sodhi, 2004; Sodhi & Brook 2006; FAO, 2006; Laurence, 2007; Henson & Chang, 2003; Buckland, 2005).

During the creation of oil palm plantations, most standing vegetation is removed by cutting, mechanical clearing, and/or burning. Use of fire for land preparation has been reported to have contributed to the problem of forest fires in Indonesia in the late 1990s

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[34] www.rspo.org

(Lebbin, 2000). Oil palm plantations can produce a positive cash flow only after a few years. Revenues from the sale of timber from logging of virgin forests may offset the costs of plantation establishment. As with other crops, it is difficult to quantify the extent to which palm oil has been a direct cause of deforestation (Fitzherbert *et al.*, 2008). Some oil palm plantations have replaced other agricultural crops like cocoa, rubber, and coconut, which have lower market values. It has been reported that half of the additional 2 million hectares of oil palm plantations established in Malaysia between 1990–2005 were from conversion of other agricultural crops, with the other half from net land expansion (Tan *et al.*, 2009).

With regard to biodiversity, oil palm plantations have been found to be a poor substitute for native tropical forests. They support few species of conservation importance, and can affect biodiversity in adjacent habitats through fragmentation, edge effects, and pollution (Fitzherbert, 2008). Even when oils palm replace other agricultural crops or degraded forests biodiversity decreases.

Peat land destruction

Peat land comprises soils with a high proportion of incompletely decomposed organic matter caused by waterlogged conditions. Globally, one third of the carbon reservoir (or an equivalent of 70 times the current annual global greenhouse gas emissions from fossil fuel burning) is stored in peat lands covering 3 percent of the earth's land surface. Through drainage, the dry peat is exposed to air and starts oxidizing, decomposing, and emitting large amounts of carbon dioxide. Additionally, drained peat land is prone to fire, further accelerating greenhouse gas releases. In Southeast Asia, large-scale drainage of former rainforest has occurred to enable logging of the peat swamp forests and the transportation of logs in the drainage canals. After deforestation, drainage continues to establish oil palm and pulp wood plantations.

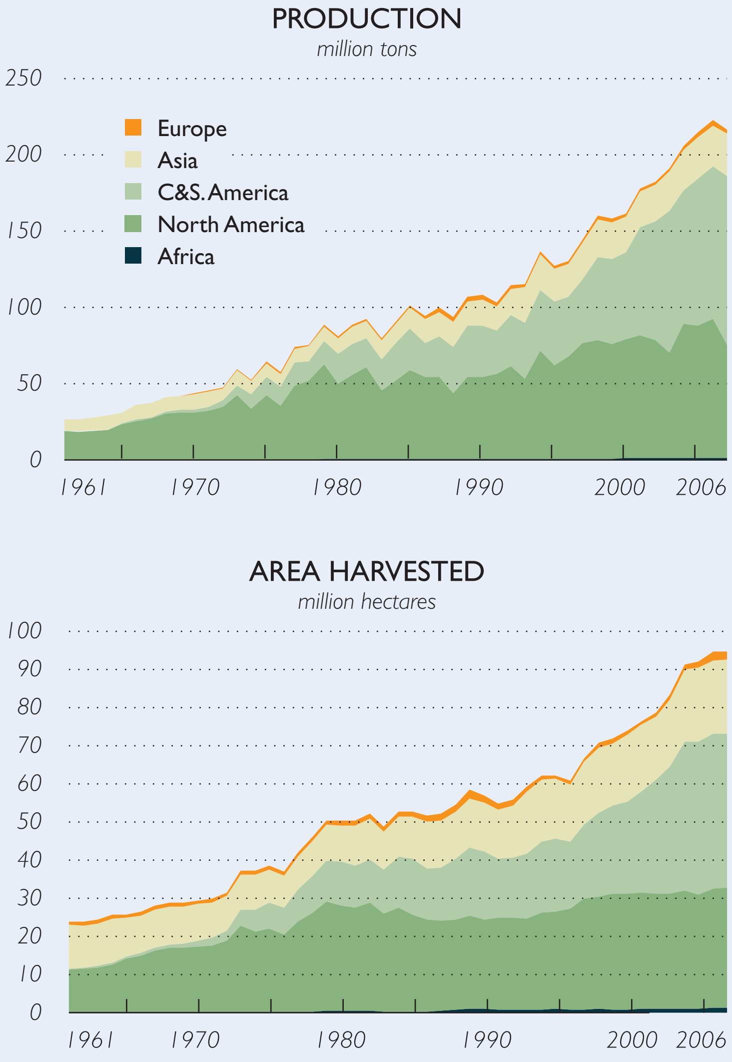
In Indonesia, nearly 25 percent of all oil palm plantations are on converted peat lands. Silvius (2006) estimated that over recent years average annual emissions from the destruction of Indonesia's extensive peat bogs released 2000 million tons of carbon dioxide per year - about ten percent of world greenhouse gas emissions from human activities. This includes 600 million tons from decomposition and 1400 million tons from fires. Beyond contributing to climate change, destruction of peat lands increases the risk of flooding.

Social conflicts

In many instances the expansion of oil palm plantations has caused social conflicts between local communities and project proponents. In their principles and criteria for sustainable palm oil production, the RSPO acknowledges this conflict, stressing compliance with local and international laws and regulations. The aim is to ensure that palm oil companies respect the local communities' ownership over their land and solve any conflicts that may arise between these two parties.

Export revenues of palm oil sales make a substantial contribution to Malaysia's and Indonesia's national GDP. High export revenues result from the availability of land and labor as cheap production factors. The contribution of oil palm cultivation to poverty alleviation depends on the structure of the palm oil industry, e.g. small holders as opposed to large private companies. However, although some progress has been made in poverty alleviation, this does not necessarily solve conflicts emerging from different perceptions on the rights of indigenous populations to preserve their traditional cultures and lifestyles. Land tenure is often a key element in conflicts over newly established oil palm plantations. In Indonesia, customary land use and land ownership is legally acknowledged, however, there are other laws which make it easy to bypass customary rights if this affects 'the national interest' (Colchester *et al.*,2006).

Global soybean production 1961-2007 by broad geographic region Figure 2.6 - 26



PRODUCTION

million tons

AREA HARVESTED

million hectares

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

Soybean

Regional distribution and dynamics of soybean production and use

'Soya' (or 'Soy' in the United States of America), is an annual legume, (*Glycine max* (L.)), that has been grown for three millennia in Asia and, more recently, has been successfully cultivated around the world. World soybean production has increased by over 500 percent during the last 40 years, due to both increased demand for the vegetable oil and growing global livestock feed requirements. Similarly, the harvested area has quadrupled to more than 90 million hectares (Figure 2.6-26). The world's main producers of soybean are the USA, Brazil, Argentina, China, and India (Table 2.6-10).

Yields have increased considerably through genetic improvements and the use of biocides and fertilizers. Over the past forty years yields more than doubled from approximately 1 ton per ha to a current 2.5 to 2.7 tons per ha in the main producing countries of the USA, Brazil, and Argentina. Only in China, the fourth largest soybean producer, are yields lower at 1.7 tons per ha.

There is wide range of soybean varieties. Genetically modified (GM) soybean[35] varieties began to be commercially grown in 1996, and they quickly became predominant in the major soybean producing countries. Traditional varieties are used in organic foods and other products for which the consumer expects a 'natural' raw material. In the world's three largest producing countries, the USA, Brazil, and Argentina, approximately 70–90 percent of soybean produced consists of GM varieties. On the consumption side, the advent of GM soybeans and other food crops has created considerable debate following consumer and environmentalists' concerns about the safety of GM products.

Globally, close to 30 percent of oilseeds produced are traded. In the case of oils, the share exceeds 40 percent (compared to less than 20 percent most grains). Although still the largest producer and soybean exporting

Major soybean producers, 1961 – 2007 Table 2.6 - 10

Production *(1000 tons)*	2007	1999-01	1989-91	1979-81	1969-71	1961
USA	70,707	75,317	52,944	54,961	31,174	18,468
Brazil	58,197	34,260	19,629	13,468	1,547	271
Argentina	45,500	22,355	9,354	3,657	39	1
China	15,600	15,021	10,323	8,266	8,381	6,264
India	9,433	6,107	2,300	359	14	5
Paraguay	3,900	3,181	1,604	616	50	2
Canada	2,785	2,373	1,314	651	257	180
Bolivia	1,900	1,013	292	49	1	0
Ukraine	836	61	0	0	0	0
EU27	803	1,370	2,214	555	112	7
Others	6,482	4,656	6,368	3,506	2,184	1,684
World	216,144	165,714	106,341	86,088	43,761	26,883

Source: FAOSTAT, online database at http://www.fao.org, accessed October 2008.

country, the United States of America has lost the dominant position it once had in global soybean production and trade. Brazil, Argentina, China, and India have all become major producers as the world's demand for soy as food, vegetable oil, and livestock feed has increased (Figure 2.6-27).

Approximately six percent of soybeans are used directly as human food (tofu, soybean milk), mostly in Asia. The bulk (85 percent) of the world's soybean crop is processed (via 'crushing' or 'oil mill' operations) into vegetable oil and meal for livestock feed. The oil component is primarily used for human consumption, although the proportion for industrial use is growing rapidly (Figure 2.6-17). Industrial uses includes production of fatty acids, soaps, varnish, or lacquer, but the recent increase in growth is due to biodiesel production based on soybean oil, especially in the USA and Argentina. In 2008–09, biodiesel production accounted for as much as 25 percent, or around 4.4 million tons, of total soybean oil usage in the USA, Argentina, Brazil, and the EU-27 (ISTA Mielke GmbH, Nov. 2008).

Sustainability of production

The rapid expansion of soybean production has resulted in several adverse ecological and social impacts. In Latin America, land clearing for monoculture plantations at the expense of primary rainforests and savannas has often destroyed local biodiversity. Wide-scale application of fertilizers and other agro-chemicals have polluted the ground and surface waters. Conflicts over land rights and labor issues have resulted in social imbalances. These concerns triggered the creation of the Round Table on Responsible Soy Association (RTRS[36]), which is in the process of developing principles and criteria for sustainable soybean production.

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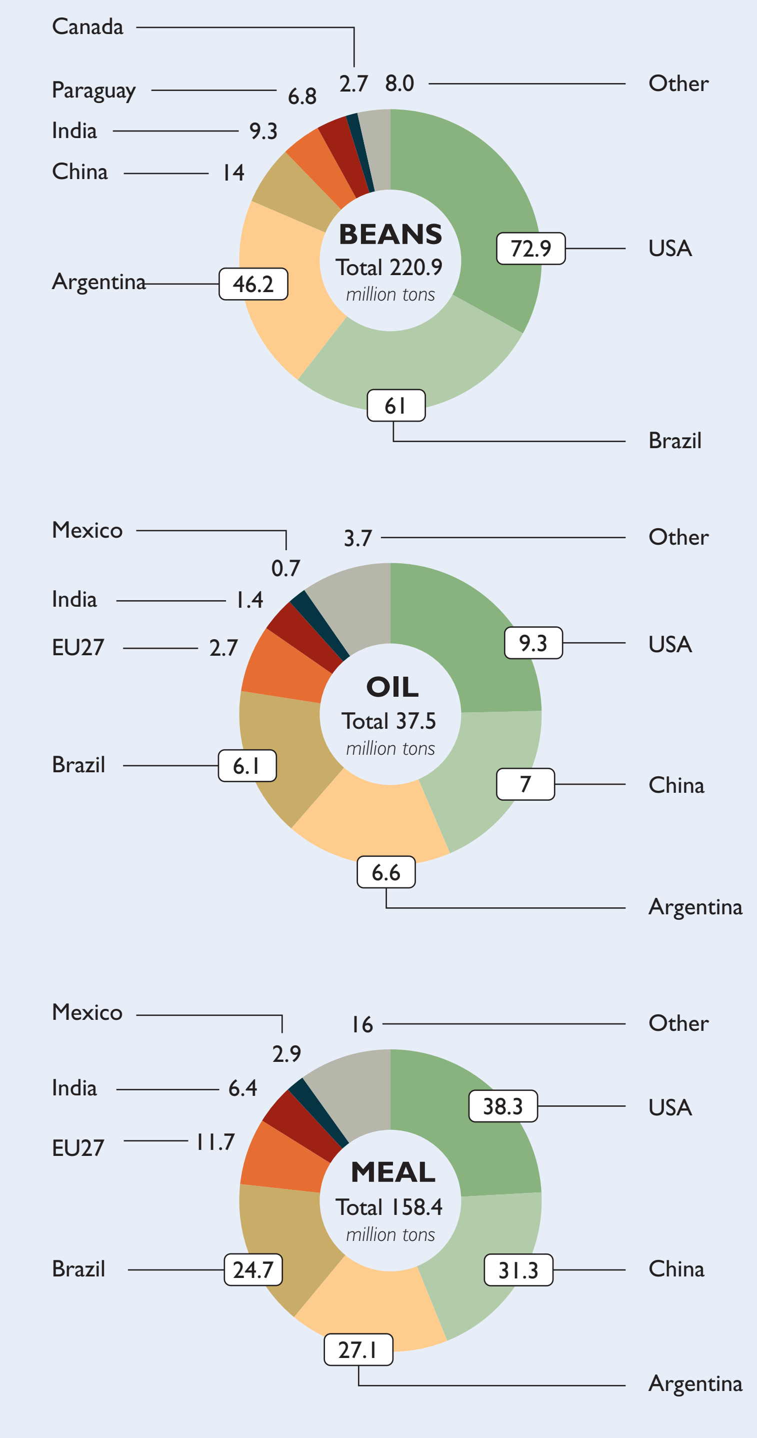
[35] Early GM soybeans were engineered to be herbicide resistant (specifically to "RoundUp Ready" glyphosate) and were thus very popular with farmers. More recent generations of GM soybeans have included traits that have benefits for oilseed processors and the consumer.

[36] www.responsiblesoy.org

Major producers of soybeans, soybean oil and meal, 2008 Figure 2.6 - 27



Source: USDA FSA, Oilseeds: World Markets and Trade, 2008.

Although much of the soybean area expansion to date has been for the production of concentrated feeds for livestock, increasing demand for biodiesel adds further momentum. In the United States of America biodiesel production soared after 2005 and reached 1.7 billion liters in 2007. While soybeans are not an efficient crop for the production of biodiesel, due to their comparatively low oil content, their common use in the USA for food and feed products has led to soybean oil becoming the primary source for USA biodiesel. Soybean producers have lobbied to increase awareness of soybean biodiesel, expanding the market for their product. Argentina promotes soybean biodiesel aimed exclusively at the export market.

Jatropha

Historical scale, regional distribution and dynamics of Jatropha production

Jatropha is native to Central America and has become naturalized in many tropical and subtropical areas, including India, Africa, and North America. As with many members of the family Euphorbiaceae, jatropha contains compounds that are highly toxic.

Due to the toxicity of its leaves jatropha is not used for livestock fodder, instead being used as protecting hedges. Jatropha oil is not edible and is traditionally used for manufacturing soap and medicinal applications. It is however, suitable for industrial processing or as an energy source to produce biodiesel.

Technology and yields

Jatropha is used to produce the non-edible jatropha oil, for making candles and soap, and as a feedstock for biodiesel. Jatropha cultivation is claimed to be useful for: soil and water conservation, soil reclamation, erosion control, living fences, firewood, green manure, lighting fuel, medicinal applications, and the seed cake supposedly makes good fertilizer. Although the toxic constituents of jatropha make it unfit for livestock, they are effective against a wide variety of pests, e.g., leaf extracts are being used as larvicides.

None of the jatropha species have been properly domesticated and, as a result, its productivity is variable. In addition, the yield performance of jatropha provenances is reported to be largely uncertain when transferred to different ecological circumstances and management.

To maintain jatropha production on sustainable levels, it is important to know that a substantial amount of nutrients are removed if the jatropha by-products are used, i.e., not returned to the soil. Environmental and management conditions have a large effect jatropha oil yields.

Jatropha potential for oil production is high in comparison with values reported for other oil crops such as soybean, sesame, sunflower, rapeseed, and castor.

Jatropha is sometimes presented as a wonder crop, but FAO (2008a) warns, "Despite considerable investment and projects being undertaken in many countries, reliable scientific data on the agronomy of jatropha are not available. Information on the relationship between yields and variables such as soil, climate, crop management and crop genetic material on which to base investment decisions is poorly documented. What evidence there is shows a wide range of yields that cannot be linked to relevant parameters such as soil fertility and water availability (Jongschaap *et al.,* 2007). Experience with jatropha plantations in the 1990s, such as the "Proyecto Tempate" in Nicaragua, which ran from 1991–1999, ended in failure (Euler and Gorriz, 2004)."

The fear that the rush into jatropha on the basis of unrealistic expectations will not only lead to financial losses, but also undermine confidence among local communities – a recurrent theme in many African countries – appears to be well founded (FAO, 2008a). Sustainable jatropha plantations will mean taking the uncertainty out of production and marketing. Further research is needed on suitable germplasm and on yields under different conditions, and markets need to be established to promote sustainable development of the crop.

Jatropha cultivation in Africa – current levels and estimates for 2015 Table 2.6 -11

Country	Cultivated land (2005)	Jatropha (2008)		Jatropha (2015)	
	ha	*ha*	%	*ha*	%
Ghana	6,385,000	2,000	0.03	600,000	9.40
Cameroon	7,160,000	3,000	0.04	13,500	0.19
Zambia	5,289,000	35,200	0.67	134,000	2.53
Mozambique	4,630,000	7,900	0.17	170,000	3.67
Madagascar	3,550,000	35,700	1.01	500,000	14.08
Malawi	2,740,000	4,500	0.16	226,000	8.25
Tanzania	10,350,000	17,600	0.17	166,000	1.60
Ethiopia	13,922,000	200	0.00	125,000	0.90
Total	54,026,000	106,100	0.20	1,934,500	3.58

Source: Global Market study on Jatropha (by GEXSI for WWF and BP)

Jatropha cultivation in Asia – current levels and estimates for 2015 Table 2.6-12

Country	Cultivated land (2005)	Jatropha (2008)		Jatropha (2015)	
	ha	*ha*	%	*ha*	%
India	169,650,000	407,000	0.24	1,900,000	1.12
Myanmar	10,956,000	850,000	7.76	4,000,000	36.51
Malaysia	7,585,000	1,700	0.02	57,000	0.75
Indonesia	36,600,000	75,500	0.21	5,200,000	14.21
Philippines	10,700,000	3,750	0.04	1,100,000	10.28
China	156,327,000	105,000	0.07	600,000	0.38
Total	391,818,000	1,442,950	0.37	12,857,000	3.28

Source: Global Market study on Jatropha (by GEXSI for WWF and BP)

Trends in usage in Asia, Africa, and Latin America

Jatropha is grown on a modest scale in plantations. In 2008, the total global area under jatropha plantations was just under 1 million ha. The majority of the plantations are found in Asia (85 percent) followed by Africa (13 percent), and Latin America (2 percent). In some countries jatropha is considered an undesirable invasive species and is banned (Australia) or excluded from any governmental support until at least 2013 (South Africa).

In Latin America, the largest jatropha plantations exist in Brazil with almost 16000 ha. Other important countries are Mexico, Colombia, and Guatemala. According to experts, the total acreage in Latin America under jatropha may rise to 2 million ha by 2015.

Jatropha has been known for generations in many countries in Sub-Saharan Africa. Traditionally it has been used as hedges and for medicinal purposes. Today significant investments in cultivating jatropha as an energy crop are occurring in Africa with large project developments currently underway in Tanzania (17000 ha), Madagascar (36000 ha), Zambia (35000 ha), and Mozambique (8000 ha). Further large-scale development is envisaged (Table 2.6-11).

Asia has by far the largest area (approximately 900,000 ha) under jatropha cultivation. Experts expect that this may increase 10 fold over the coming 7 years to more than 9 million ha. The largest jatropha plantations exist in India (407,000 ha), Myanmar (850,000 ha) China (105,000 ha), and Indonesia (75,000 ha) (Table 2.6-12).

Jatropha by-products

Jatropha seed cake is toxic and therefore only suitable for livestock feed after processing, which is a complicated process due to the several toxic components involved. However, laboratory-scale detoxification has been successful. Other by-products such as fruit coats, seed hulls and the remaining de-oiled seed cake after pressing may be used as organic fertilizers.

Global significance of biodiesel production from Jatropha

Jatropha is claimed to produce high quality oil highly suitable for bio-diesel production[37]. However, global production to date is negligible. Recent substantial investments in jatropha plantations indicate that prospects are regarded as promising.

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[37] Global Market study on jatropha by GEXSI for WWF and BP and jatropha project in India financed by a.o., Daimler Ag Stuttgart and Deutsche Investitions and Entwicklungsgesellschaft AG MBH

2.6.4
Second-generation biofuels

Introduction

Extensive use of biofuels requires expansion of the range of feedstocks and the introduction of advanced conversion technologies, such as Fischer-Tropsch synthesis, and ethanol production from lignocellulosic feedstocks using a biochemical pathway.

Second-generation biofuel feedstocks include herbaceous lignocellulosic species, such as miscanthus, switchgrass, and reed canary grass, and woody lignocellulosic tree species including poplar, willow, and eucalypt. Residues from agricultural crops and forests, and forest products containing cellulose, also qualify as feedstocks.

A key challenge for second-generation technology chains is to develop conversion technologies at industrial scales and competitive prices. These technologies require large-scale feedstock supplies with associated challenges for logistics and management. At the farm level, more fundamental and difficult-to-reverse land use changes will be inevitable.

Herbaceous lignocellulosic feedstocks

Important perennial grasses include switchgrass and miscanthus (highly productive C4 species and the more cold tolerant reed canary grass (a slightly less productive C3 species). Switchgrass especially is claimed to produce well on marginal sites. All three grasses are generally harvested once a year.

These perennial grasses, particularly miscanthus, have low fertilizer demands as compared to agricultural crops and the woody lignocellulosic feedstock species. This is due to greater nutrient use efficiency and the capacity to recycle large amounts of nutrients into the rhizomes during the latter part of the growing season, which are then re-used for producing new shoots.

Characteristics of perennial grasses

Box 2.6 - 1

Miscanthus originates from East Asia and includes a number of ornamental varieties. Its high yield potential for cellulose fiber production was established in the 1960s and has subsequently spread, especially throughout Europe. Its extensive underground rhizome system is a storage organ for nutrients and forms shoots every year. From the second season onwards miscanthus grows to a height of 2.5–3.5 m. Miscanthus is productive for over 15 years (up to 25 years), which compensates for the relative high cost of planting material (Lewandowski *et al*, 2003).

Reed canary grass is native to temperate regions of Europe, Asia, and North America. It has been used as a fodder crop for horses and for erosion control. Recently, interest in reed canary grass has focused on material and energy uses with research currently underway in Sweden, Finland, Denmark, and the UK. Reed canary grass can be characterized as a sod forming perennial wetland grass with a commercial production cycle between 10–15 years without new establishment.

Switchgrass is native to North America where it is widely distributed. Like miscanthus and reed canary grass, switchgrass has a very well developed rooting system. There are two distinct ecotypes; upland ecotypes, which are less productive than the lowland ecotypes, but can be used in cooler environments and are more tolerant to drought. Lowland ecotypes are taller, have thicker stems, and are more resistant to problems like rust than the upland types. Switchgrass, which can grow up to 3 m in height and has a lifespan of more than 10 years, is adapted to a wide variety of soil conditions. Switchgrass breeders are focusing on high yields combined with high cellulose ration and low ash content. In addition, research is being undertaken on new propagation techniques, physiology, and molecular genetics (McLaughlin *et al*., 1999).

Woody lignocellulosic feedstocks

Short-term rotation coppice (SRC) of trees such as willow, poplar, and eucalypt is a widespread technology popular with energy producers. Willow and poplar are especially suited for temperate climate conditions while eucalypt species are adapted to subtropical and tropical climatic conditions.

SRC crops can be easily harvested, chipped and transported. An additional advantage is the potential for dual use as windbreaks and field hedges. These SRC tree species may have a positive impact on groundwater purification and create important habitats for fauna and flora. Some disadvantages, compared to perennial grasses include:

- higher initial investment requirements,
- specialized know-how and new or modified field equipment is required,
- somewhat lower productivity as compared to competing C4 perennial grasses,
- more reliance on fertilizer,
- more problems with pest diseases with the cloned planting materials used,
- not well adapted to marginal soils with low water holding capacity,
- more expensive harvesting process, and
- even more difficult to reconvert SRC land back to agriculture. Conversion is also costly in terms of greenhouse gas balance.

Global significance of second-generation biofuel technologies

While first-generation biofuel technologies are at an advanced stage and widely used in many countries, second-generation technologies are still mainly in experimentation and demonstration phases. To prepare for the large-scale use of cost-competitive second-generation biofuels, continued research and development is needed.

Sustainability aspects

Bio-energy feedstocks for second-generation technology chains produce relatively high energy yields with modest use of agro-chemicals and low tillage intensities. In particular, second-generation production pathways can reduce net greenhouse gas emissions.

The production of lignocellulosic energy crops differs from conventional crops in several respects. As first-generation biofuel feedstocks are well known to farmers and simply involve alternative uses of conventional crops, no major changes in agricultural management are required. These feedstocks can be integrated in rotations with food and feed crops and support farmers' flexibility to respond to market conditions. In contrast, successful introduction and production of lignocellulosic feedstocks will entail substantial changes in agricultural management.

Feedstocks for second-generation biofuels permit a wider spectrum of land to be considered, notably grassland, which is generally unsuitable for first-generation biofuels due to environmental and greenhouse gas implications. These could become a valuable resource for producing high-yielding lignocellulosic feedstocks under zero or minimum tillage systems. Marginal areas may also be considered for these types of feedstock production under low-input agricultural management systems.

Conversion of annual crop land into perennial lignocellulosic energy feedstock plantations needs careful considerations beyond agronomic and economic factors. The large-scale establishment of especially the longer-rotation options would also lead to far reaching changes in the traditional agricultural/cultural landscape. In Europe, the use of arable land for lignocellulosic feedstocks will involve modifying current regulations and spatial policies both at the national level and in the Common Agricultural Policy (CAP).

2.7. Assessment of production potentials of major agricultural feedstocks for biofuels

2.7.1
Introduction

The range of land uses for human needs is limited by environmental factors including climate, topography, and soil characteristics, and is primarily determined by demographic and socioeconomic drivers, cultural practices, and political factors, such as land tenure, markets, institutions, and agricultural policies.

FAO, in collaboration with IIASA, has developed a system (the Agro-ecological Zones (AEZ) methodology) that enables rational land-use planning based on an inventory of land resources, and evaluation of biophysical limitations and production potentials. .

This FAO/IIASA global agro-ecological zones modeling framework (GAEZ) has been used for the global assessment of production potentials of selected bio-fuel feedstocks, listed in Table 2.7-1.

The selection of feedstocks for the assessment is based on their global importance for either ethanol and biodiesel production chains (see section 2.6). For biodiesel production jatropha feedstock has been included, although jatropha currently occupies less than 1 million ha globally for biofuel purposes. Table 2.7-2 provides the relative agricultural importance of the selected first-generation feedstocks by comparing current harvested areas with total cultivated land

Second-generation feedstocks selected include current important herbaceous and woody lignocellulosic plant species. The assessment of potentials for second-generation feedstocks has been combined with a separate Net Primary Production (NPP) capacity assessment.

Selected biofuel feedstocks Table 2.7 - 1

Technology	Feedstock	Pathway	Product
First-generation	Sugarcane	sugar	ethanol
First-generation	Maize	starch	ethanol
First-generation	Cassava	starch	ethanol
First-generation	Rape	vegetable oil	biodiesel
First-generation	Soybean	vegetable oil	biodiesel
First-generation	Oil palm	vegetable oil	biodiesel
First-generation	Jatropha	vegetable oil	biodiesel
Second-generation	Herbaceous ligno-cellulosic plants*	biomass	cellulosic ethanol, F-T diesel, etc.
Second-generation	Woody ligno-cellulosic plants**	biomass	cellulosic ethanol, F-T diesel, etc.

* Explicitly included are: Switchgrass, Miscanthus and Reed canary grass
** Explicitely included are: Poplar, Willow and Eucalyptus

Harvested areas of selected first-generation biofuel feedstocks (Mha) Table 2.7 - 2

REGIONS	CULTIVATED LAND	2007 HARVESTED AREA					
		Sugarcane	Maize	Cassava	Rape	Soybean	Palm oil
North America	230	0.4	36.4	0.0	6.3	31.7	0.0
Europe & Russia	305	0.0	13.9	0.0	8.2	2.0	0.0
Oceania & Polynesia	53	0.5	0.1	0.0	1.1	0.0	0.1
Asia	559	9.7	48.8	3.8	14.5	19.4	8.9
Africa	244	1.6	29.0	11.9	0.1	1.3	4.3
Central Amer.& Carib.	43	1.8	10.0	0.2	0.0	0.1	0.2
South America	129	8.0	19.7	2.7	0.1	40.4	0.4
Developed	591	0.8	50.4	0.0	15.6	33.7	0.0
Developing	972	21.2	107.5	18.7	14.7	61.2	13.9
World	1,563	22.0	157.9	18.7	30.2	94.9	13.9

2.7.2
Agro-ecological zones methodology

The AEZ methodology follows an environmental approach provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. Crop modeling and environmental matching procedures are used to identify crop-specific limitations of prevailing climate, soil, and terrain resources, under assumed levels of inputs and management conditions. This part of the AEZ methodology provides maximum potential and agronomically attainable crop and biomass yields globally at 5-minute latitude/longitude resolution grid-cells.

Box 2.7-1 summarizes the AEZ methodology and information flow as applied for the assessment of global bio-fuel feedstock potentials.

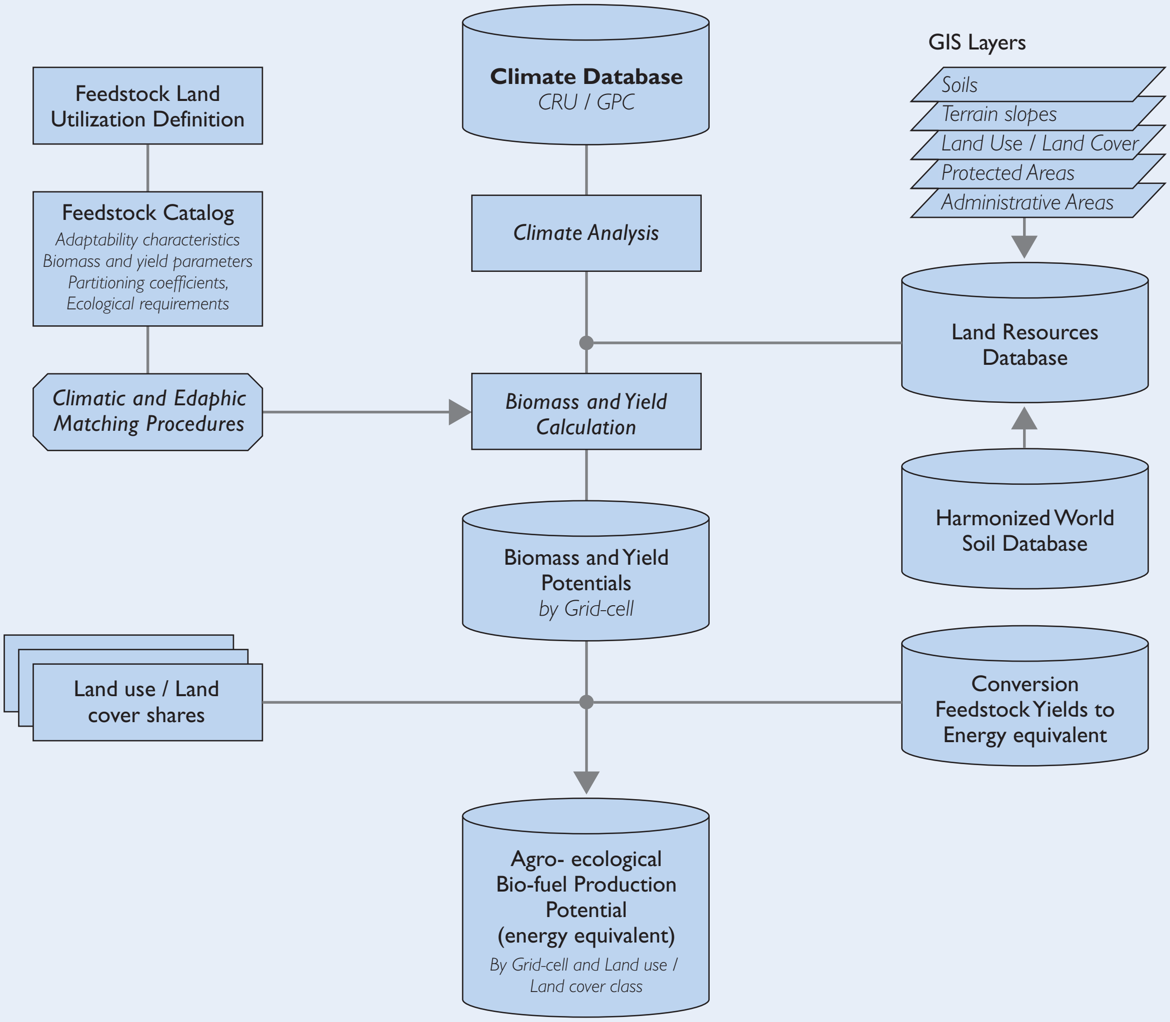
AEZ procedures

Box 2.7 - I

Land Utilization Type (LUT): The AEZ procedures have been used to derive, by grid-cell, potential biomass and yield estimates for rain-fed biofuel feedstock production under a high level of inputs/ advanced management, which includes the main socio-economic and agronomic/farm-management components: The farming system is (i) market oriented; (ii) commercial production of biofuel feedstocks are management objectives, and (iii) production is based on currently available yielding cultivars, is fully mechanized with low labor intensity, and assumes adequate applications of nutrients and chemical pest, disease and weed control.

AEZ methodology – information flow and integration

Figure 2.7 - I



The quantified description of biofuel feedstock LUTs include characteristics such as vegetation period, ratoon practices, photosynthetic pathway, photosynthesis in relation to temperature, maximum leaf area index, partitioning coefficients, and parameters describing ecological requirements of biofuel feedstock produced under rain-fed conditions.

Climatic data: Climate data are from the Climate Research Unit (CRU CL 2.0 (New et al., 2002, CRU TS 2.1; Mitchell & Jones, 2005), and precipitation data from VASClimO (Global Precipitation Climatology Centre - GPCC). Average climate and historical databases were used to quantify: (i) the length of growing period parameters, including year-to-year variability, and (ii) to estimate for each grid-cell by crop/LUT, average and individual years agro-climatically attainable biofuel feedstock yields.

Soils data: Spatial soil information and attributes data is used from the recently published Harmonized World Soil Database (FAO, IIASA, ISRIC, ISS-CAS & JRC, 2008)

Terrain data: Global terrain slopes are estimated on the bases of elevation data available from the Shuttle Radar Topography Mission (SRTM) at 3 arc-second resolution

Land use/land cover: Potential yields, suitable areas and production were quantified for different major current land cover categories (Fischer et al., 2008a). The estimation procedures for estimating seven major land-use and land cover categories are as follows: Cultivated land shares in individual 5' grid cells were estimated with data from several land cover datasets: (i) the GLC2000 land cover regional and global classifications (http://www.gvm.jrc.it/glc2000), (ii) the global land cover categorization, compiled by IFPRI (IFPRI, 2002), based on a reinterpretation of the Global Land Cover Characteristics Database (GLCC) version 2.0, EROS Data Center (EDC, 2000) (iii) the Forest Resources Assessment of FAO (FAO, 2001a), and global 5' inventories of irrigated land (GMIA version 4.0; FAO/University of Frankfurt, 2006). Interpretations of these land cover data sets at 30-arc-sec. were used to quantify shares of seven main land use/land cover, consistent with land use estimates of published statistics. These shares are: cultivated land, subdivided into (i) rain-fed and (ii) irrigated land, (iii) forest, (iv) pasture and other vegetation, (v) barren and very sparsely vegetated land, (vi) water, and (vii) urban land and land required for housing and infrastructure.

Protected areas: The principal data source of protected areas is the World Database of Protected Areas (WDPA) (http://www.unep-wcmc.org/wdpa/index.htm.) Two main categories of protected areas are distinguished: (i) protected areas where restricted agricultural use is permitted, and (ii) strictly protected areas where agricultural use is not permitted.

Land resources

Database: Spatial data linked with attribute information from soils, terrain, land use and land cover, and protected areas are combined with an administrative boundary GIS layer in the land resources database

Climate analysis: Monthly reference evapotranspiration (ETo) has been calculated according to Penman-Monteith. A water-balance model provides estimations of actual evapotranspiration (ETa) and length of growing period (LGP). Temperature and elevation are used for the characterization of thermal conditions, e.g., thermal climates, temperature growing periods (LGP_t), and accumulated temperatures. Temperature requirements of biofuel feedstock were matched with temperature profiles prevailing in individual grid-cells. For grid-cells with an optimum or sub-optimum match, calculations of biomass and yields were performed.

Edaphic modifiers: The edaphic suitability assessment is based on matching of soil and terrain requirements of the assumed bio-fuel feedstock production systems with prevailing soil and terrain conditions.

Land productivity for rain-fed biofuel feedstock production: The combination of climatic and edaphic suitability classification provides by grid-cell potential biomass and yield estimates for assumed production conditions

Box 2.7-1

2.7.3

Global potential of biofuel feedstocks

Results of the AEZ analysis show considerable global potentials for the various biofuel feedstocks considered.

Considering all currently cultivated land (approximately 1.6 billion hectares), all unprotected grasslands and woodlands (3.4 billion hectares) and all unprotected forestland (2.8 billion hectares) - combined covering 7.8 billion hectares, or approximately 60 percent of the global landmass excluding Antarctica[38] - we find that globally, land potentially suitable[39] for individual feedstocks varies between approximately 2.2 billion hectares for soybean, approximately 1.8 billion hectares for maize, about 1.6 billion hectares jatropha to just over 600 million hectares for oil palm (Table 2.7-3a)

The picture is different when considering only land that is currently being cultivated. Maize is potentially suitable on more than 800 million hectares of existing cultivated land, followed by soybean and rape potentially suitable on 700–800 million hectares. Area-wise, oil palm has the least potential, at just over 80 million hectares (5 percent) of the cultivated land. (Table 2.7-3b)

On land that is currently not protected grassland and woodland, the potentials for biofuel feedstocks are considerable. Almost 700 million hectares, or approximately 20 percent, of this land is suitable for soybean, about 580 million hectares for maize and some 470 million hectares are suitable for jatropha. The potential for oil palm is remarkably low at approximately 1 percent (Table 2.7-3c).

Unprotected forestland presents a completely different picture. Jatropha, cassava and soybean are suitable across about 700 million hectares, i.e. 25 percent of this forestland. Oil palm, in contrast with the current cultivated land and grassland/woodland areas, is potentially suitable for a very significant part of this forestland at almost 500 million hectares or just over 17 percent (Table 2.7-3d).

Potential suitable areas for selected biofuel feedstocks (Mha) Table 2.7 - 3a

REGIONS	ASSESSED LAND	POTENTIALS *for all cultivated land and unprotected grassland, woodland and forest land*						
		Sugarcane	Maize	Cassava	Rape	Soybean	Oil palm	Jatropha
North America	1,116	44	233	7	380	227	0	58
Europe & Russia	1,583	0	169	0	440	62	0	1
Oceania & Polynesia	647	17	78	28	50	71	14	29
Asia	1,464	149	335	209	235	362	94	246
Africa	1,484	288	633	536	209	785	135	581
Central Amer. & Carib.	183	28	50	31	21	52	14	42
South America	1,2990	554	329	620	202	614	362	620
Developed	3,332	48	479	20	876	352	0	73
Developing	4,444	1,032	1,347	1,410	662	1,821	616	1,504
World	7,777	1,081	1,827	1,430	1,537	2,175	616	1,577

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[38] Apart from Antarctica, land not considered in the assessment, are protected grass land and woodland, protected forestland, barren land, urban areas and water bodies.

[39] Under potentially suitable land, all land that is very suitable, suitable and moderately suitable is considered; land that is only marginally or very marginally suitable has been discarded.

Potential suitable areas for selected biofuel feedstocks (Mha)

Table 2.7 - 3b

REGIONS	CULTIVATED	POTENTIALS FOR CULTIVATED LAND						
	LAND	Sugarcane	Maize	Cassava	Rape	Soybean	Oil palm	Jatropha
North America	230	16	131	4	181	128	0	20
Europe & Russia	305	0	133	0	241	54	0	1
Oceania & Polynesia	53	2	5	2	20	7	1	2
Asia	559	97	281	142	168	295	45	168
Africa	244	57	167	99	58	170	19	103
Central Amer. & Carib.	43	16	26	18	8	28	6	25
South America	129	77	80	79	60	110	13	91
Developed	591	16	270	4	445	190	0	21
Developing	972	248	552	340	291	601	83	389
World	1,563	265	823	344	735	792	83	409

Potential suitable areas for selected biofuel feedstocks (Mha)

Table 2.7 - 3c

REGIONS	NOT PROTECTED	POTENTIALS *for currently not protected grassland and woodland*						
	Grassland and woodland	Sugarcane	Maize	Cassava	Rape	Soybean	Oil palm	Jatropha
North America	452	2	7	1	31	17	0	5
Europe & Russia	459	0	13	0	45	5	0	0
Oceania & Polynesia	496	2	49	8	13	38	2	8
Asia	511	8	18	10	38	19	5	18
Africa	878	70	326	188	92	346	12	219
Central Amer. & Carib.	71	4	10	4	6	10	2	6
South America	541	141	154	178	103	247	25	211
Developed	1,400	3	68	7	89	58	0	10
Developing	2,007	225	509	382	239	625	44	456
World	3,408	228	577	389	328	683	44	467

Large tracts of the world's combined cultivated land, unprotected grassland, woodland and unprotected forestland, are suitable for successful production of herbaceous and woody cellulosic feedstocks. In total almost 40 percent of this land or just over 3 billion hectares are suitable. In South America alone nearly 1 billion hectares or 76 percent of this land is suitable. There is no single first-generation feedstock that can match the large suitable extents of lignocellulosic feedstocks. Of the unprotected grassland and woodlands alone world-wide 25 percent or about 860 million hectares would be suitable for the production of ligno-cellulosic feedstocks.

Potential suitable areas for selected biofuel feedstocks (Mha)

Table 2.7 - 3d

REGIONS	NOT PROTECTED FOREST	POTENTIALS *for currently not protected forest land*						
		Sugarcane	Maize	Cassava	Rape	Soybean	Oil palm	Jatropha
North America	434	26	95	2	168	82	0	33
Europe & Russia	819	0	23	0	154	3	0	0
Oceania & Polynesia	98	13	24	18	17	26	11	20
Asia	394	44	36	57	29	48	44	60
Africa	362	161	140	249	59	269	104	258
Central Amer. & Carib.	69	8	14	9	7	14	6	11
South America	629	336	95	363	39	257	324	318
Developed	1,341	29	141	9	342	104	0	42
Developing	1,465	559	286	688	132	595	489	659
World	2,806	588	427	697	474	700	489	700

Note: Potentials of individual feedstocks are not additive.

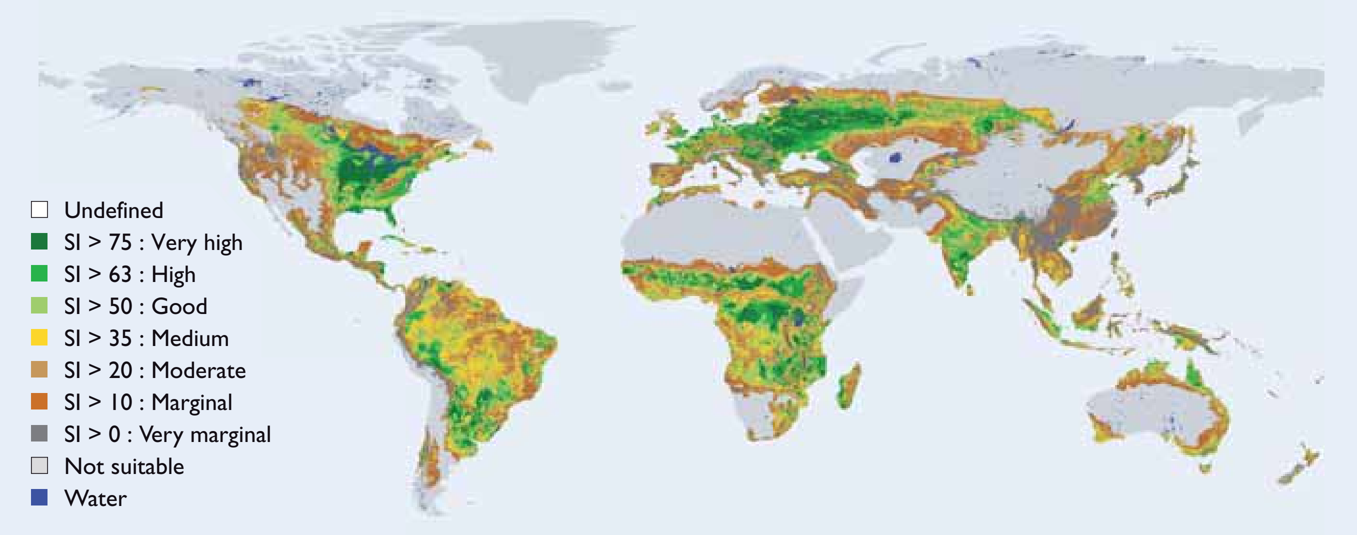
Suitability for rain-fed lignocellulosic feedstocks (Mha)

Table 2.7 - 3e

REGIONS	CULTIVATED LAND, UN-PROTECTED GRASS-, WOOD- AND FORESTLAND			UN-PROTECTED GRASS- AND WOODLAND		
	Totals	Very-, suitable, moderately suitable		Totals	Very-, suitable, moderately suitable	
	Mha	*Mha*	*%*	*Mha*	*Mha*	*%*
North America	1116	293	26	452	30	7
Europe & Russia	1583	168	11	459	18	4
Oceania & Polynesia	648	156	24	496	80	16
Asia	1464	501	34	511	33	6
Africa	1483	823	55	878	356	41
Central Amer./Car.	183	81	44	71	17	24
South America	1298	981	76	541	326	60
Developed	3332	600	18	1400	124	9
Developing	4444	2404	54	2007	735	37
World	7776	3003	39	3408	859	25

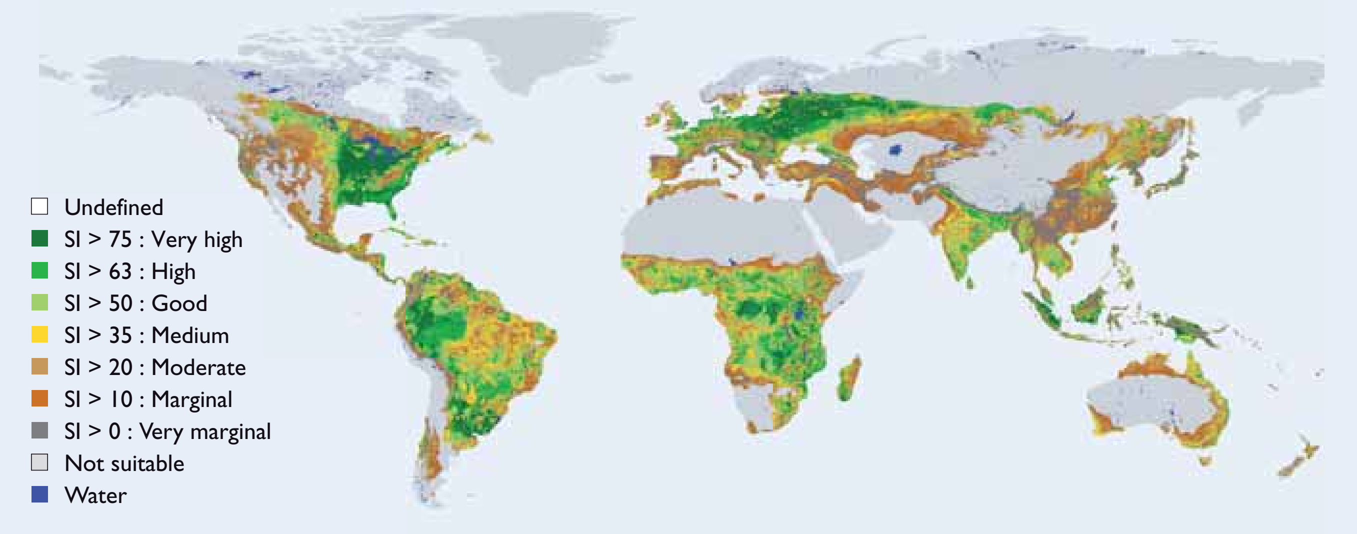
Global land suitability for first-generation feedstocks for ethanol (sugar cane, maize and cassava)

Figure 2.7 - 2



Global land suitability for first-generation feedstocks for biodiesel (rape, soybean, oil palm, and jatropha)

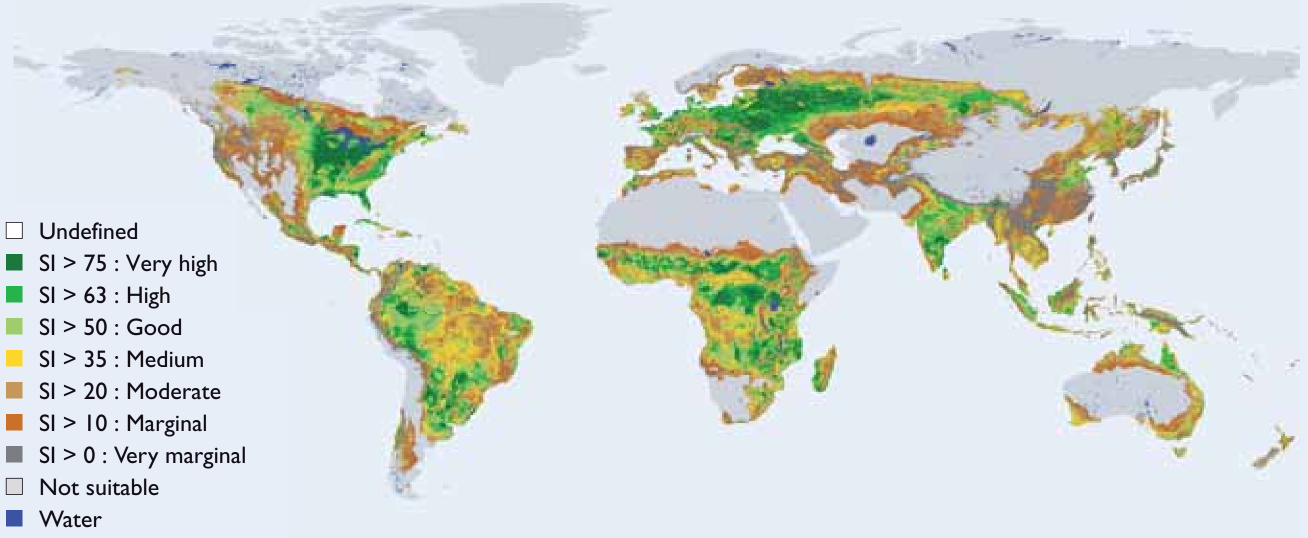
Figure 2.7 - 3



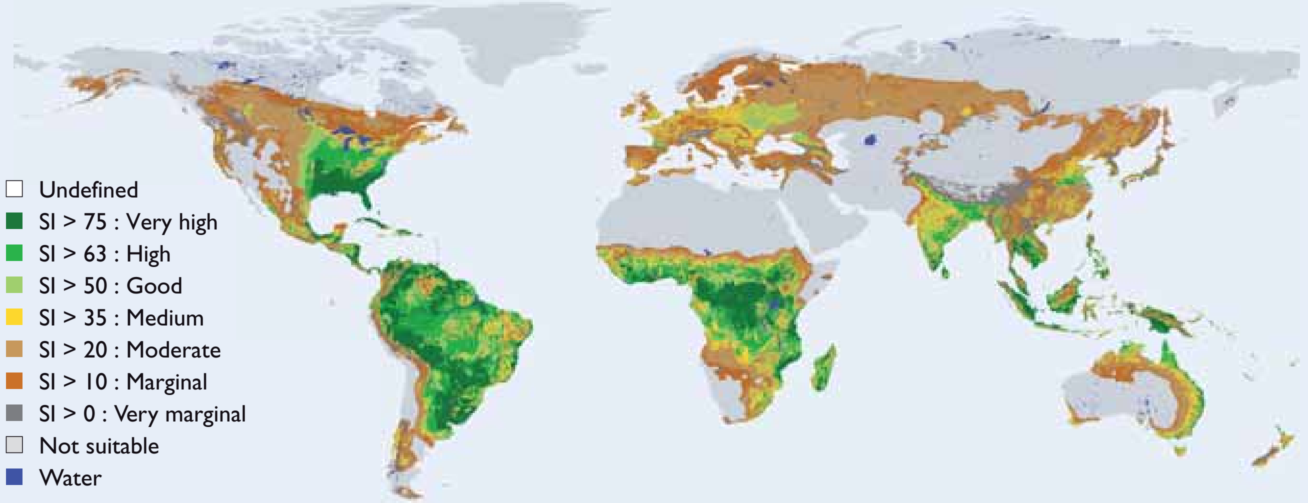
Figures 2.7-2, 2.7-3, 2.7-4, and 2.7-5 present the global spatial distribution of agro-ecological potentials for, respectively: (i) first-generation feedstocks for ethanol production (sugar cane, maize, and cassava); (ii) first-generation feedstocks for biodiesel production (rapeseed, soybean, palm oil, and jatropha); (iii) first-generation feedstocks for ethanol and biodiesel production together, and (iv) second-generation herbaceous and woody ligno-cellulosic feedstocks production.

In order to represent both yield potentials and suitable extent distributions within pixels, a suitability index SI[40] has been used.

Global land suitability for first-generation biofuel feedstocks Figure 2.7 - 4



Global land suitability for second-generation feedstocks (herbaceous and woody lignocellulosic plant species) Figure 2.7 - 5



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[40] Suitability index *SI* is reflecting the spatial suitability make-up of a pixel in accordance with the definition of suitability classes below, namely as: $SI = VS*0.9 + S*0.7 + MS*0.5 + mS*0.3$.

	Suitability class	Percentage of maximum yield
VS	Very Suitable land	80–100
S	Suitable land	60–80
MS	Moderately Suitable land	40–60
mS	Marginally Suitable land	20–40

Part III: **Biofuels, Food Security and Environmental Impacts**

3.1 Introduction

Liquid transport biofuels, mainly ethanol and biodiesel, are produced from a number of agricultural crops that are also important for the provision of food and feed. At present biofuels production is spreading around the world in a growing number of countries.

A number of developed countries have embraced the apparent win-win opportunity to foster the development of biofuels in order to respond to the threats of climate change, to lessen their dependency on oil and to contribute to enhancing agriculture and rural development, which is also of concern to developing countries where more than 70 percent of the poor reside in rural areas. Countries such as the United States, members Member States of the European Union, China, India, Indonesia, South Africa and Thailand have all adopted policy measures and set targets for the development of biofuels.

The driving forces of biofuels expansion have been foremost huge subsidies and the mandates and targets set by national governments. Whilst the justification of biofuels targets to enhance fuel energy security and to contribute to climate change mitigation and agricultural rural development is appealing, the reality is complex since the consequences of biofuels developments result in local, national, regional and global impacts across interlinked social, environmental and economic domains, well beyond the national setting of domestic biofuels targets.

The conditioning factors of biofuels development at national level include the technical capabilities of biofuels as blending agents, the agro-ecological conditions and availability of land resources, the suitability, productivity and production potential of various biofuel feedstocks, the prospects for regional and international trade of biofuels, and the potential savings of greenhouse gas emissions and climate change mitigation. An integrated agro-ecological and socioeconomic spatial approach with world-wide coverage is important to assess the spatially diverse risks and benefits of biofuels expansion at national, regional and global levels.

IIASA's modeling framework and models have been developed to analyze spatially the world food and agriculture system and evaluate the impacts and implications of agricultural policies. The modeling framework has recently been extended and adapted to explicitly incorporate the issues of biofuel development. A brief summary of the methods and models applied and the scope and limitations in this study is presented below.

3.2 Methodology and data

The modeling framework

The study is based on a state-of-the-art ecological-economic modeling approach. The scenario based quantified findings of the study rely on a modeling framework which includes as components, the FAO/IIASA Agro-ecological Zone model and the IIASA global food system model. The modeling framework encompasses climate scenarios, agro-ecological zoning information, demographic and socio-economic drivers, as well as production, consumption and world food trade dynamics.

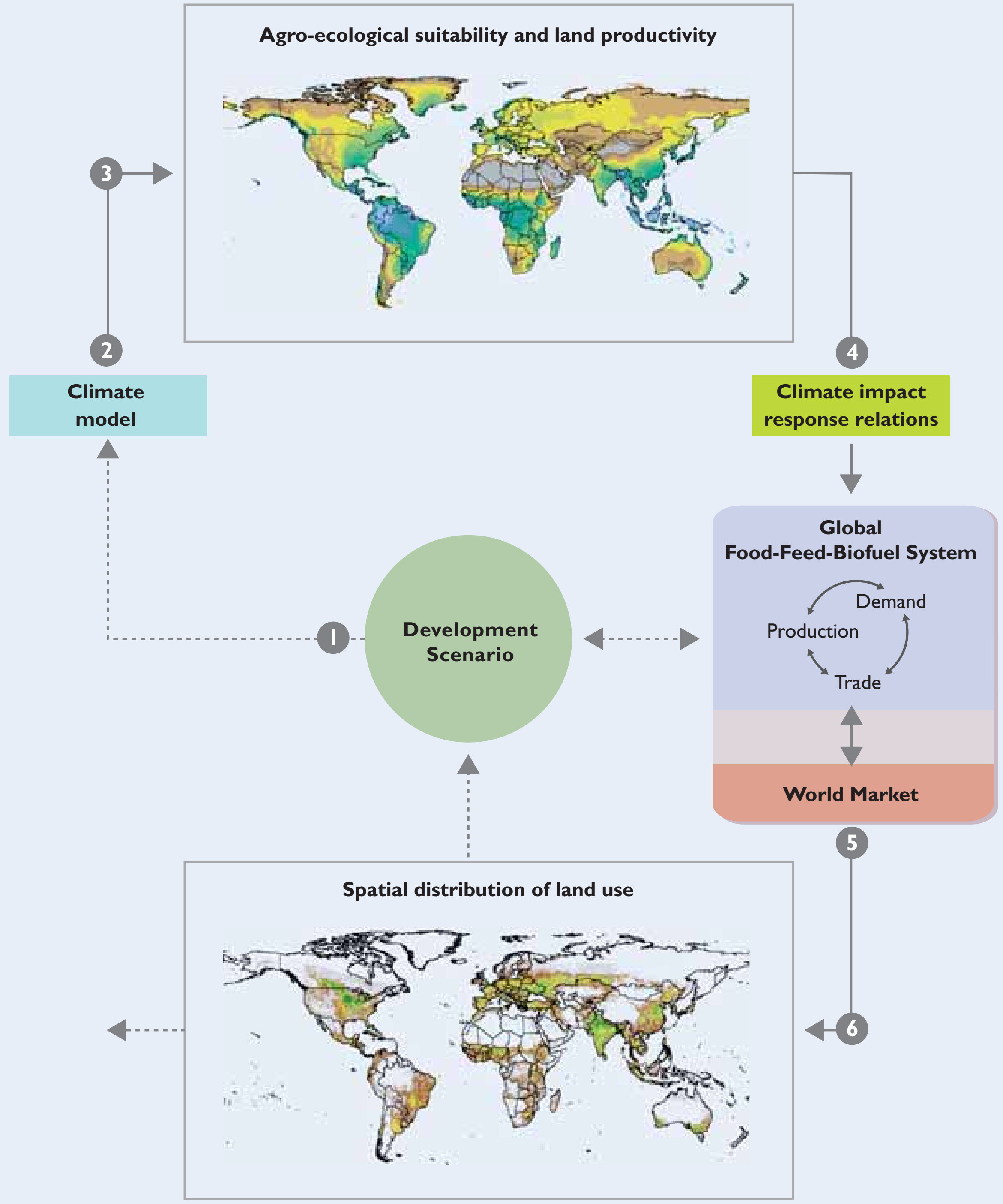
This modeling framework comprises six main elements, as sketched in Figure 3.2-1:

1. A storyline and quantified development scenario (usually chosen from the extensive integrated assessment literature) is selected to inform the world food system model of demographic changes in each region and of projected economic growth in the non-agricultural sectors. It also provides assumptions characterizing in broad terms the international setting (e.g. trade liberalization; international migration) and the priorities regarding technological progress. It quantifies selected environmental variables, e.g. greenhouse gas emissions and atmospheric concentrations of CO_2. In this study it also defines scenarios of demand for first- and second-generation biofuels.
2. The emission pathway associated with the chosen development scenario is used to select among available and matching published outputs of simulation experiments with general circulation models (GCMs). The climate change signals derived from the GCM results are combined with the observed reference climate to define future climate scenarios.
3. The agro-ecological zones (AEZ) method takes as input a climate scenario and estimates on a spatial grid of 5’ by 5’ latitude/longitude the likely agronomic impacts of climate change and identifies adaptation options.
4. Estimated spatial climate change impacts on yields for all crops are aggregated and incorporated into the parameterization of the national crop production modules of a regionalized world food system model.
5. The global general equilibrium world food system model is used – informed by the development storyline and estimated climate change yield impacts – to evaluate internally consistent world food system scenarios.
6. In a final step, the results of the world food system simulations are ‘downscaled’ to the spatial grid of the resource database for quantification of land cover changes and a further analysis of environmental implications of biofuels feedstock production.

AEZ methodology

The AEZ modeling uses detailed agronomic-based knowledge to simulate land resources availability, assess farm-level management options and estimate crop production potentials. It employs detailed spatial biophysical and socio-economic datasets to distribute its computations at fine gridded intervals over the entire globe (Fischer et al., 2002a; 2005). This land-resources inventory is used to assess, for specified management conditions and levels of inputs, the suitability of crops in relation to both rain-fed and irrigated conditions, and to quantify expected attainable production of cropping activities relevant to specific agro-ecological contexts. The characterization of land resources includes components of climate, soils, landform, and present land cover.

Framework for ecological-economic world food system analysis Figure 3.2 - 1



Crop modeling and environmental matching procedures are used to identify crop-specific environmental limitations, under various levels of inputs and management conditions.

In summary, the AEZ framework contains the following basic elements (see also description in Chapter 2.7):

- Land resources database, containing geo-referenced climate, soil and terrain data;
- Land Utilization Types (LUT) database of agricultural production systems, describing crop-specific environmental requirements and adaptability characteristics, including input level and management.
- Mathematical procedures for matching crop LUT requirements with agro-ecological zones data and estimating potentially attainable crop yields, by land unit and grid-cell (AEZ global assessment includes 2.2 million land grid cells at 5’ by 5’ latitude/longitude);
- Assessments of crop suitability and land productivity;
- Applications for agricultural development planning.

World food system model

The world food system model comprises a series of national and regional agricultural economic models. It provides a framework for analyzing the world food system, viewing national food and agricultural components as embedded in national economies, which in turn interact with each other at the international trade level. The model consists of 34 national and regional geographical components covering the world. The individual national/regional models are linked together by means of a world market, where international clearing prices are computed to equalize global demand with supply (see Box 3.2).

Simulations with the world food system model generate a variety of outputs. At the global level these include world market prices, global population, global production and consumption. At the country level it includes producer and retail prices, levels of production, use of primary production factors (land, labor, and capital), intermediate input use (feed and fertilizer), human consumption, use for biofuel production, and commodity trade, value added in agriculture, investment by sector and income by group and/or sector.

Population growth and technology are key external inputs to the model system. Population numbers and projected incomes are used to determine demand for food for the period of study. Technology affects yield estimates, by modifying the efficiency of production per given units of inputs and land. For simulations of historical periods up to the present, population data are taken from official U.N. data at country-level, while the rate of technical progress has been estimated from past agricultural performance.

To assess agricultural development over the next decades to 2050, with and without biofuel expansion, it was necessary to first make some coherent assumptions about how key socio-economic drivers of food systems might evolve over that period. For this purpose we have chosen a recent update undertaken at IIASA (Riahi et al, 2006) of widely used development scenarios described for the IPCC *Special Report on Emissions Scenarios* (SRES) (Nakicenovic et al., 2000). We focused on a new socioeconomic scenario developed at IIASA, to quantify global and regional socio-economic development from 1990 to 2050, with associated climate change variables. This particular scenario, labeled as ‘revised SRES A2’ scenario or ‘A2r’, represents a major numerical revision of the original SRES A2 scenario of the IPCC, which reflects more recent long-term demographic outlooks and economic projections not available at the time of the IPCC SRES (Riahi et al., 2006).

Another external input to the model system is projected climate change, which affects region-specific crop suitability and

How does the world food system work?

Box 3.2 - 1

The world food system model is an applied general equilibrium (AGE) model system. While focusing on agriculture, this necessitates that also all other economic activities are represented in the model. Financial flows as well as commodity flows within a country and at the international level are kept consistent in the sense that they must balance, by imposing a system of budget constraints and market-clearing conditions. Whatever is produced will be demanded, either for human consumption, feed, biofuel use, or as intermediate input. Alternatively, commodities can be exported or put into storage. Consistency of financial flows is imposed at the level of the economic agents in the model (individual income groups, governments, etc.), at the national as well as the international level. This implies that total expenditures cannot exceed total income from economic activities and from abroad, in the form of financial transfers, minus savings. On a global scale, not more can be spent than what is earned.

Each individual model component focuses primarily on the agricultural sector, but includes also a simple representation the entire economy as necessary to capture essential dynamics among capital, labor and land. For the purpose of international linkage, production, consumption and trade of goods and services are aggregated into nine main agricultural sectors. The nine agricultural sectors include: wheat; rice; coarse grains; bovine and ovine meat; dairy products; other meat and fish; oilseed cakes and protein meals; other food; non-food agriculture. The rest of the economy is coarsely aggregated into one simplified non-agricultural sector. Agricultural commodities may be used in the model for human consumption, feed, as biofuel feedstock, for intermediate consumption, and stock accumulation. The non-agricultural commodity contributes also as investment, and as input for processing and transporting agricultural goods. All physical and financial accounts are balanced and mutually consistent: the production, consumption, and financial ones at the national level, and the trade and financial flows at the global level.

Linkage of country and country-group models occurs through trade, world market prices, and financial flows. The system is solved in annual increments, simultaneously for all countries in each time period. Within each one-year time period, demand changes with price and commodity buffer stocks can be adjusted for short-term supply response. Production in the following marketing year (due to time lags in the agricultural production cycle) is affected by changes in relative prices. This feature makes the world food model a recursively dynamic system.

The market clearing process results in equilibrium prices, i.e., a vector of international prices such that global imports and exports balance for all commodities. These market-clearing prices are then used to determine value added in production and income of households and governments.

Within each regional unit, the supply modules allocate land, labor and capital as a function of the relative profitability of the different crop and livestock sectors. In particular, actual cultivated acreage is computed from both agro-climatic land parameters (derived from AEZ) and profitability estimates. Once acreage, labor and capital are assigned to cropping and livestock activities, yields and livestock production is computed as a function of fertilizer applications, feed rates, and available technology.

The IIASA world food system model has been calibrated and validated over past time windows and successfully reproduces regional consumption, production, and trade of major agricultural commodities in 2000. Several applications of the model to agricultural policy and climate-change impact analysis have been published (e.g., Fischer et al., 1988; Fischer et al., 1994; Rosenzweig and Parry, 1994; Fischer et al., 2002b; Fischer et al., 2005; Tubiello and Fischer, 2006).

attainable yields. This spatial agronomic information (derived from AEZ) is used in an aggregate form by the economic model as an input in allocating land and agricultural inputs (Fischer et al., 2005). In this study the atmosphere-ocean GCM developed by the UK Hadley Center for Climate Prediction and Research is used to take into account climate change impacts on land suitability and productivity.

The evaluation of the potential impacts on production, consumption and trade of agricultural commodities, caused by a rapid expansion of global biofuel use, was carried out in two steps. First, simulations were undertaken representing "futures" where biofuel production was frozen at current levels (i.e. of year 2008) and kept constant for the remainder of the simulation period. Second, alternative levels of biofuel demand, as derived from different energy scenarios, were simulated with the food system model and compared to the respective outcomes without additional biofuels demand.

The primary role of a reference scenario is to serve as "neutral" point of departure, from which various biofuel scenarios take off as variants, with the impact of biofuel expansion being seen in the deviation of these simulation runs from the outcomes of the reference scenario. The simulations were carried out on a yearly basis from 1990 to 2050.

Study scope and limitations

This study presents a comprehensive evaluation of the social, environmental and economic impacts and implications of biofuels development on transport fuel security, greenhouse gas emissions, agricultural prices, food security, land use change and sustainable agricultural development. These results need to be considered in the context of following scope and limitations of the study:

- This study focuses on bioethanol and biodiesel as the main liquid transport biofuels currently in use and considered in national planning to 2020. A wider range of liquid biofuels are envisaged to become available with second-generation technologies and may become important in the longer term.
- The scenario analysis relies on only one transport fuel scenario, namely the energy model derived reference scenario published in the World Energy Outlook 2008 by the International Energy Agency. The biofuels development scenarios in this study have been constructed on the basis of each country's biofuel targets as announced. The scenario analysis takes into account policies currently in place but does not make assumptions on specific additional policies and measures, e.g. to regulate land use for biomass production, to compensate 'losers' for negative impacts , to limit biofuels options imposing minimum GHG saving requirements etc.
- The study addresses social and environmental impacts for alternative scenarios of expanding liquid transport biofuels use and no specific consideration is given to possible other uses of biomass in the stationary energy sectors. The study assesses the agronomic feasibility of biofuels targets but does not apply cost criteria to judge their economic viability;
- There are large uncertainties regarding the speed of second generation technologies development and deployment as well as costs and efficiencies. In the scenario analysis a plausible range for a possible contribution of second-generation feedstocks is considered via scenario variants, as proposed by current literature and expert opinion.
- The assessments of net greenhouse gas emissions from biofuels presented in the study are subject to a considerable uncertainty range both with regards to life cycle results as well as land use change impacts.

How is spatial land conversion determined?

Box 3.2 - 2

Land conversion in the integrated assessment framework (Figure 3.2-1) is explicitly modeled to maintain full consistency between the spatial agro-ecological zones approach used for appraising land resources and land productivity and the expansion of cultivated land as determined in the world food system model. The conversion of agricultural land is allocated to the spatial grid in 10-year time steps by solving a series of multi-criteria optimization problems for each of the countries/regions of the world food system model.

The modeling framework (i) characterizes spatial land productivity and its current uses, (ii) uses land cover interpretations for the base year 2000 together with statistical data from the FAO to construct comprehensive spatial land accounts in terms of area shares for seven main land use/land cover classes, (iii) informs the world food system model of physical resource availability and characteristics, and (iv) updates in regular time steps the spatial resource data base and estimated spatial use consistent with the aggregate outcomes of the world food system model.

The criteria used in the land conversion module depend on whether there is a projected net decrease or increase of cultivated land in the region of consideration. In the case of a decrease the main criteria and drivers include demand for built-up land and abandonment of marginally productive cultivated land. In case of increases of cultivated land the land conversion algorithm takes land demand from the world food system equilibrium and applies several constraints and criteria, including: (i) the total amount of land converted from and to agriculture in each region of the world food system model, (ii) the productivity, availability and current use of land resources in each country/region of the world food system model, (iii) suitability of land for conversion to crop production, (iv) legal land use limitation, i.e. protection status, (v) spatial suitability/propensity of ecosystems to be converted to agricultural land, i.e. a priority ranking of ecosystems with regard to land conversion, and (vi) land accessibility, i.e. in particular a grid-cell's distance from existing crop production activities.

To ensure comparability across scenarios the above criteria, rules and parameterization guiding land conversion have been kept the same for all scenario simulations in this study.

The range of individual biofuels feedstocks emissions information available in the literature has been used for both aspects and the study results are qualified accordingly and indicate ranges of possible outcomes.

- There are considerable uncertainties in regional and global future socio-political developments and climate change. The results reported in this study incorporate future climate change as projected by the Hadley Center General Circulation Model. Agronomic impacts using several other climate models have also been assessed but are not reported in the study as their differences add little to the biofuels analysis for 2020 and 2030. At present alternative demographic and political scenarios, which may alter the long-term perspectives of food and agriculture are being developed for analysis and will be reported in future work.

3.3 Overview of biofuels scenarios

The biofuel scenarios used in the model simulations were designed to cover a wide and plausible range of possible future demand for biofuels. Scenario specification consisted of three steps: first, an overall energy scenario was selected, detailing as one of its components the regional and global use of transport fuels. Second, pathways were chosen as to the role played by biofuels in the total use of transport fuels. Third, the assumptions were made explicit as to the role and dynamics of second-generation biofuel production technologies in each scenario, or conversely, what fraction of total biofuel production was expected to be supplied by first-generation feedstocks, i.e. being based on conventional agricultural crops (maize, sugar cane, cassava, oilseeds, palm oil, etc.).

Projections of transport fuel use

For describing regional energy futures we used the World Energy Outlook (WEO 2008) reference scenario as recently published by the International Energy Agency (IEA, 2008a). In the WEO 2008 Reference Scenario, world primary energy demand grows by 1.6 percent per year on average in 2006-2030, from 11,730 Mtoe to just over 17,000 Mtoe (i.e. by about 45 percent). This projection embodies the effects of government policies and measures that were enacted or adopted up to mid-2008. The IEA World Energy Model (WEM) - a large-scale mathematical system designed to replicate how energy markets function – has been the principal tool used to generate the sector-by-sector and fuel-by-fuel projections by region or country (IEA, 2008a).

World primary oil demand in the WEO reference scenario increases from 76.3 million barrels per day in 2000 to 106.4 million barrels per day in 2030, an increase by about 40 percent. The transport sector contributes about three-quarters of the projected increase in world oil demand (IEA, 2008a).

In terms of total final consumption of transport fuel the scenario projects an increase from 2227 Mtoe to 3171 Mtoe for the period 2006-2030. Regional totals of transport fuel consumption, derived from the WEO reference scenario for the period 1990 to 2030 and extrapolated to 2050 for use in the simulations of the world food system, are summarized in Table 3.3-1.

In the developed countries transport fuel use continues to increase until about 2020 (1480 Mtoe up from about 1235 Mtoe in 2000). In the period beyond 2020 it is projected to decline somewhat, reaching a level of 1460 Mtoe in 2030, mainly due to gains in fuel use efficiency and partly also due to demographic and the related transport capacity demand. In the USA and EU the fuel use in 2020 is estimated at 1090Mtoe, equivalent to nearly 75 percent of the developed world's fuel use and roughly 40 percent of world transport fuel use (excluding international bunkers and international aviation). The latter share falls to 36 percent in 2030 and to 30 percent in 2050.

The transport fuels use in the developing world increases more than three-fold from 365 Mtoe in 1990 to 1175 Mtoe in 2020, and another 30 percent by 2030, thereby exceeding the transport fuel consumption in developed countries. China, India and Brazil in total

Final consumption of transport fuels by region Table 3.3 - I

WEO	MILLION TONS OIL EQUIVALENT (Mtoe)			
	2000	2020	2030	2050
North America	655	773	773	781
Europe & Russia	519	658	652	609
Pacific OECD	105	110	99	93
Rest of World	6	16	24	36
Africa	45	69	80	122
Asia, East	114	337	495	625
Asia, South	111	224	322	544
Latin America	149	253	285	332
Middle East & N. Africa	108	214	259	342
Developed	1236	1480	1460	1417
Developing	576	1174	1529	2068
World *	1962	2830	3171	3750

* World totals include international marine bunkers and international aviation

account for some 485 Mtoe in 2020, equivalent to 41 percent of the fuel consumption in the developing world. By 2030 the consumption of these three countries is projected to reach 730 Mtoe, equivalent to a 48 percent share of the developing world's transport fuel use.

Biofuels use and share in total final consumption of transport fuels

The level and regional pattern of transport fuel consumption, as described above, has been applied in all simulations of the world food system model reported here. However, as regards the use of biofuels we have implemented two main alternative scenarios: (i) based on the WEO 2008 projections, and (ii) based on the mandates and targets announced by several developed and developing countries. In addition, a number of sensitivity scenarios were specified to gain understanding over a wider range of possible biofuel production levels.

Biofuels consumption in the WEO scenario

Final demand of biofuels in 1990 was about 6 Mtoe, with two-thirds being produced in Brazil at that time. In 2006 world biofuel consumption reached 24.4 Mtoe, with the United States being both the largest producer and consumer. In our implementation for 2020, final consumption of biofuels in the developed countries is projected at 63 Mtoe, with the United States and EU-27 accounting for 90 percent of this use. In 2030 the final consumption of biofuels reaches 79 Mtoe in the developed world. For 2030 and 2050 we use projections of biofuel consumption in developed countries that respectively amount to 79 Mtoe and 124 Mtoe[41].

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[41] Minor adjustments to values published in the WEO 2008 for developed countries have been implemented for use in the world food system simulations.

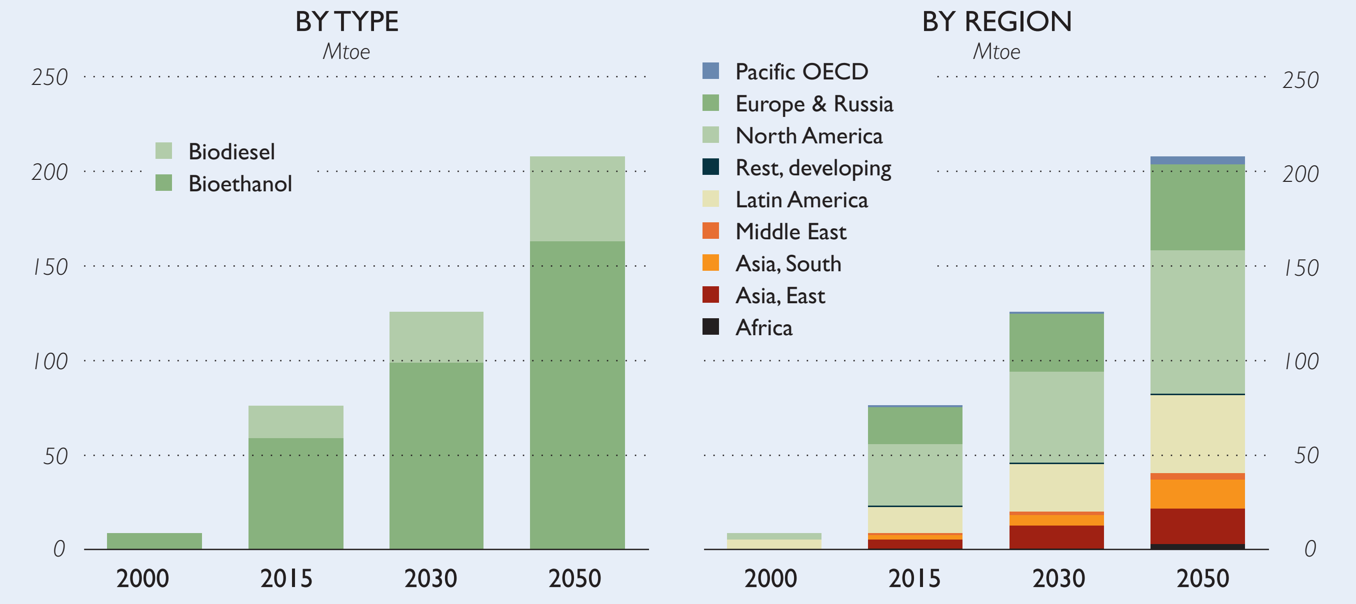
Amongst the developing countries Brazil has been the pioneer producing about 5 Mtoe in 1990 and this is projected to increase to some 18 Mtoe in 2020. Total biofuel consumption in developing countries starts from about 5.5 Mtoe in 2000, increases to 31 Mtoe by 2020, and reaches 46 Mtoe in 2030. Biofuel use in developing countries in this scenario is dominated by Brazil throughout the projection period. Brazil, China and India together account for about 80 percent of biofuel use in developing countries, a combined share that decreases slightly to about 75 percent in 2050. Figure 3.3-1 shows the dynamics of projected biofuel consumption in the WEO-based scenario; panel a) indicates the fuel split, panel b) shows a distribution by region.

Biofuels consumption in the TAR scenario

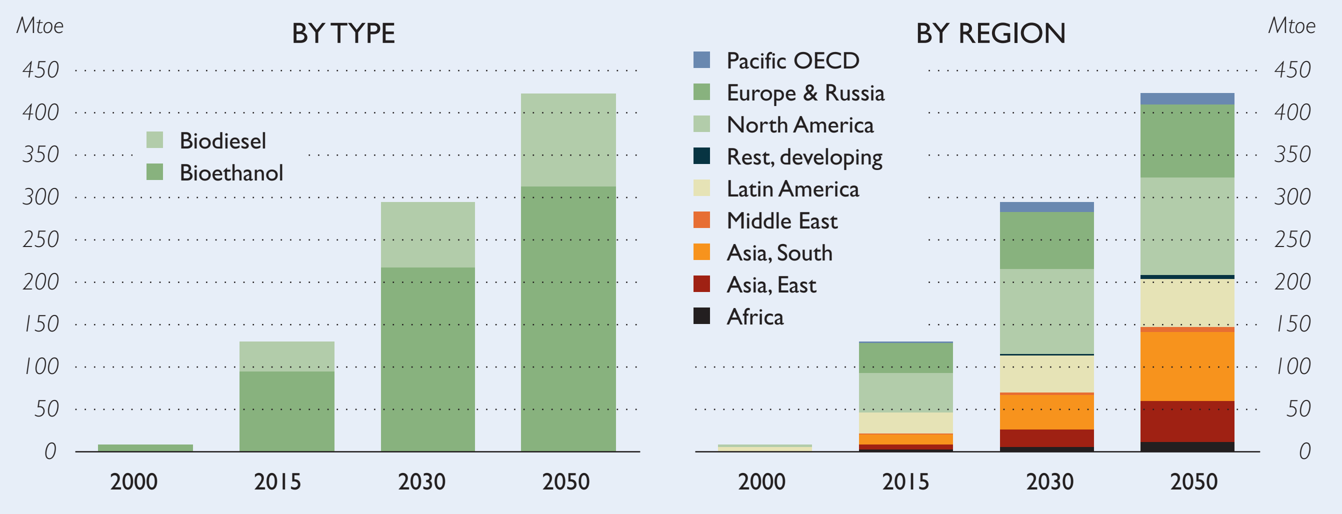
The WEO 2008 report states that "... assume in the Reference Scenario that the biofuel mandates in China and the European Union will be met after a lag of a few years but that biofuels in the United States in 2030 will attain only about 40 percent of the very ambitious target in the 2007 Energy Independence and Security Act. Asia and OECD Europe experience faster rates of growth, but in absolute terms these increases trail those in the larger North American market. Biofuels demand in the OECD Pacific region remains modest. Growth in Latin America is moderate, a consequence of the sizeable share of the market in Brazil already held by biofuels." (IEA, 2008a, p.172)

As discussed in Chapter 2.2, a number of countries have defined mandatory, voluntary or indicative targets for transport fuels (see Table 2.2-2). To gain a better understanding of the impacts on the world food system that may result from implementation and full achievement of the specified targets, a second

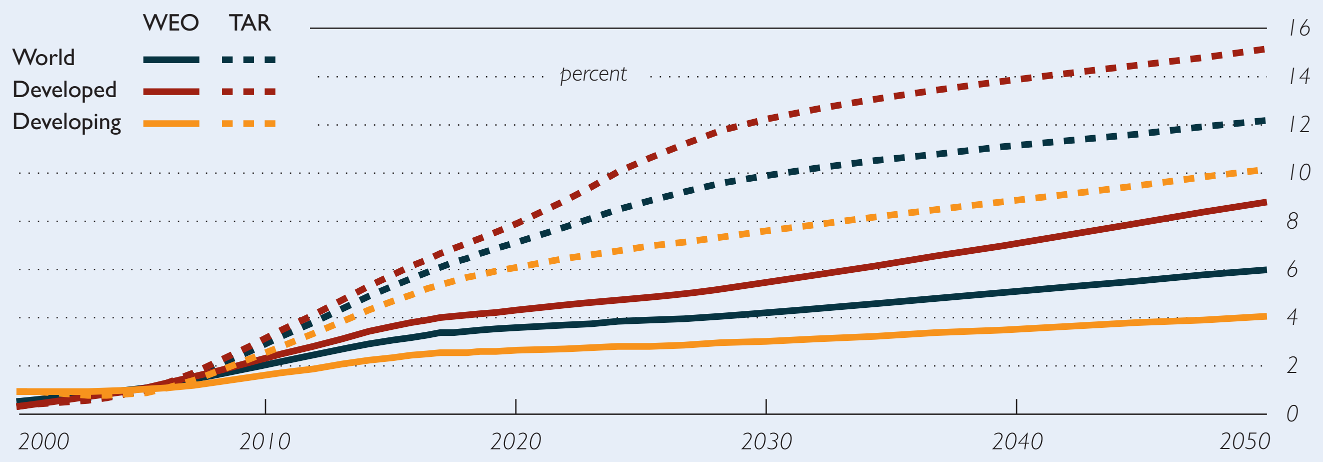
Final consumption of biofuels in the WEO scenario Figure 3.3 - 1



Final consumption of biofuels in the TAR scenario Figure 3.3 - 2



Share of biofuels in final consumption of total transport fuels Figure 3.3 - 3



biofuels scenario, more ambitious than the WEO outlook, was implemented and termed target scenario (TAR). In this scenario, final consumption of biofuels increases to 189 Mtoe in 2020, about twice the value achieved in WEO, and climbs to 295 Mtoe and 424 Mtoe respectively in 2030 and 2050. As hardly any country has announced biofuel targets beyond ca. 2020, this scenario should be interpreted as the extension of a rapid and ambitious biofuel development pathway based on targets announced up to 2020. It approximately doubles biofuel consumption compared to the WEO projections. Figure 3.3-2 shows distribution of biofuel consumption by type and region for the TAR scenario.

It is worth noting that in this TAR scenario the share of developing countries in total biofuel consumption is higher than in the WEO scenario due to considering fairly ambitious proposed or announced targets for China, India, Indonesia and Thailand. Due to this change in the regional distribution, the share of biodiesel in total biofuels increases somewhat.

Share of biofuel consumption in total transport fuels

In the developed world, the projected share of biofuel consumption in total transport fuels use in 2020 amounts to 4.3 percent in the WEO scenario. By 2030 this share increases to 5.5 percent. For the developing world the WEO scenario projects a biofuels share in total transport fuel use in 2020 and 2030 at 2.7 percent and 3.0 percent respectively. At the global level this share comes to 3.5 percent in 2020 and 4.2 percent in 2030. It increases to 6 percent in 2050[42]. With a road transport share of 70 percent-75 percent of total transport fuel use, biofuels would account for respectively 4.5 percent, 5.4 percent, and 7.6 percent of road transport in 2020, 2030 and 2050[43].

Share of second-generation biofuels in total biofuel consumption

In recent years second-generation biofuels, i.e. fuels produced from woody or herbaceous non-food plant materials as feedstocks, have attracted great attention because they are seen as superior to conventional feedstocks in terms

Scenario variants for share of second-generation biofuels in total Table 3.3 - 2

Scenario variant	Region	Assumed share of second-generation ethanol in total bioethanol (%)			
		2015	2020	2030	2050
WEO-V1, TAR-V1	United States	Starts	7.5	25	50
	Other OECD	None	Starts	12.5	33
	Russia	None	Starts	5	20
	Brazil/China/India	None	Starts	5	20
	Other developing	None	None	None	None
WEO-V2, TAR-V2	All countries	None	None	Starts	10
WEO-V3	United States	10	24	40	66
	EU-27	None	10	33	50
	Other OECD	None	10	33	50
	Russia	None	5	20	40
	China/India	Starts	5	20	40
	Other developing	0	0	10	20
TAR-V3	United States	10	35	55	70
	EU-27	10	31	47	67
	Other OECD	10	31	47	67
	Russia	Starts	10	33	50
	China/India	Starts	10	33	50
	Other developing	0	Starts	10	33

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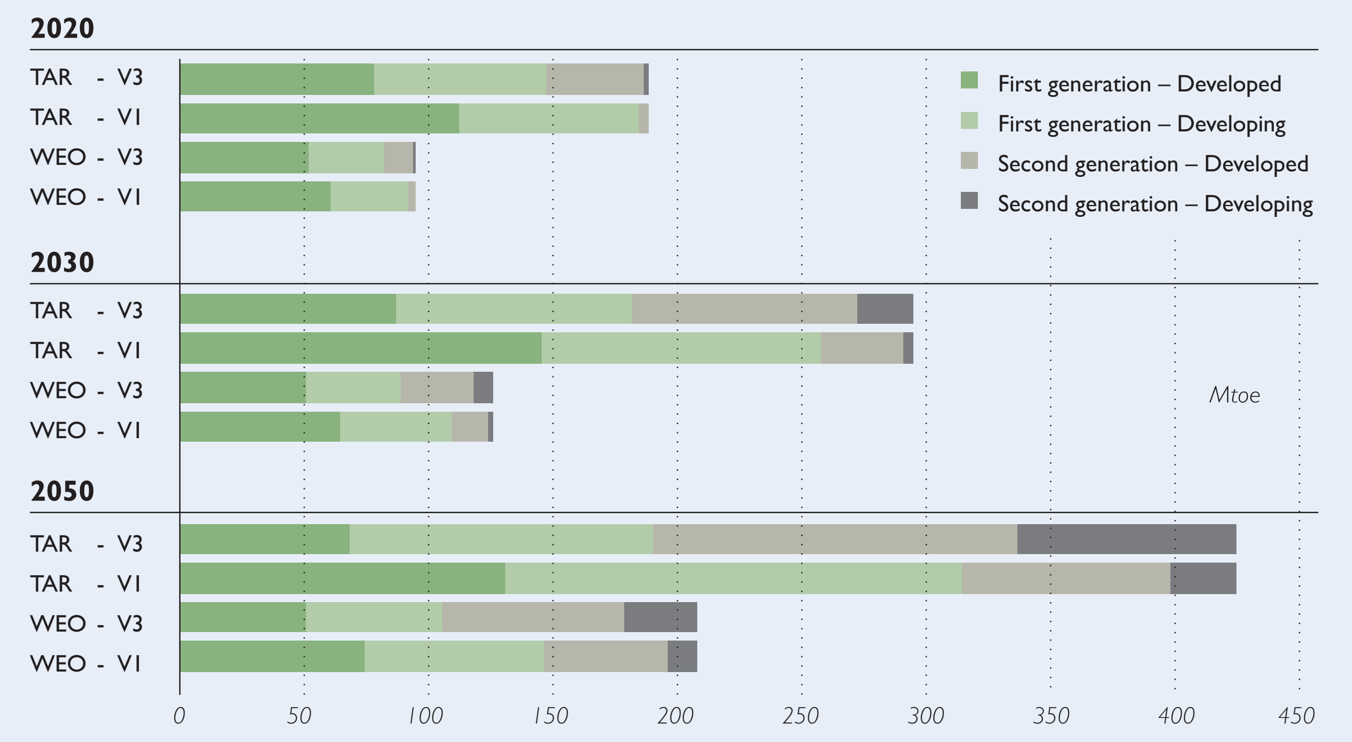
[42] Share in world total excludes international marine bunkers.

[43] Recent industry tests suggest that biofuels could also be successfully used in aviation.

Biofuel scenarios by type of technology and by broad regions Figure 3.3 - 4



of their greenhouse gas saving potential, but even more so because of their potential for production on 'non-food' land (see also discussion in section 2.8 and section 3.6).

It is widely acknowledged that major technological breakthroughs will be required to improve feedstock materials and the efficiency of the conversion process before second-generation biofuels will be able to make a significant contribution.

For completing the definition of biofuel scenarios in this study, we specified three variants for both the WEO and TAR biofuel scenario. They represent alternative views/expectations on the dynamics of technology deployment for second-generation fuels. The variants are defined by describing different pathways for the share of second-generation fuels in total biofuel consumption. Specification was done by broad regions and follows simple and transparent assumptions. The assumptions used for ethanol are summarized in Table 3.3-2[44].

The V1 variant assumes that second-generation biofuel technologies will be available in the United States for commercial deployment as of 2015. By 2020, the lignocelluloses conversion will contribute 7.5 percent of total bioethanol, and by 2030 this share will increase to 25 percent. In other OECD countries it is assumed for this scenario variant that second-generation conversion plants will take off as of 2020, occupying a share of 12.5 percent by 2030. The biofuel champions among developing countries (Brazil, China and India) will also start using second-generation technologies in 2020, but deployment would follow a somewhat slower path to contribute only 5 percent of ethanol in 2030. The V2 variant portrays a delayed development of second-

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[44] Assumptions for second-generation diesel are very similar to those for ethanol except that United States follows the same path as EU-27 and other OECD countries.

generation technologies. Conversion plants are assumed to become available only by 2030, implying that all biofuel production must rely on conventional feedstocks.

Finally, scenario variant V3 assumes an early and accelerated deployment of second-generation technologies. In scenario variant TAR-V3 the biochemical ethanol processing and FT-diesel plants become already available in 2010 and contribute in OECD countries a share of 10 percent to biofuels by 2015, increasing to more than 30 percent in 2020. In 2030, second-generation biofuels account for about 50 percent of total biofuels in developed countries, and more than two-thirds in 2050. China and India follow this development with a short delay. The share of second-generation biofuels in these two countries is set at 10 percent in 2020, one-third in 2030, and half of total biofuel production in 2050. Other developing countries start deploying second-generation plants in 2020 and reach a share of 10 percent and 33 percent respectively in 2030 and 2050. In scenario variant WEO-V3, with a lower overall ambition for biofuel production compared to the level reached in the TAR scenario, deployment of second-generation technologies is also less ambitious than in TAR-V3. It is assumed that 40 percent of biofuels in the US and one-third in other OECD countries would be second-generation biofuels by 2030. The amount of biofuel consumption in different scenario variants, by broad region and type of technology, is shown in Figure 3.3-4.

At the aggregate global level, second-generation biofuel shares in scenario variant WEO-V1 are 3 percent, 13 percent and 30 percent in 2020, 2030 and 2050 respectively. In scenario variant TAR-V1 these shares are somewhat lower (2 percent, 12 percent, and 26 percent) due to the higher shares in total production achieved by developing countries in the TAR scenario as compared to the WEO scenario.

For variant WEO-V3, second-generation shares become 13, 30 and 50 percent in 2020, 2030 and 2050 respectively. For variant TAR-V3, with an assumed accelerated second-generation development and deployment path, the respective shares are 22, 38, and 55 percent.

Sensitivity analysis with respect to share of biofuels in total transport fuels

In addition to the WEO and TAR biofuel scenarios introduced above, four sensitivity scenarios (SNS) were computed in order to systematically scan the world food system model outcomes for a broad range of imposed first-generation biofuel production levels, from 2-8 percent in 2020 and 2.5-10 percent in 2030. Table 3.3-3 summarizes for different scenarios and time points the assumed share of first-generation biofuels in total transport fuel use.

First-generation biofuels assumed in sensitivity scenarios Table 3.3 - 3

Scenario	Share in total transport fuels (percent)			first-generation biofuel consumption (Mtoe)		
	2020	*2030*	*2050*	*2020*	*2030*	*2050*
SNS-V1	2	2.5	3	54	76	106
SNS-V2	4	5	6	107	151	211
SNS-V3	6	7.5	9	161	227	317
SNS-V4	8	10	12	214	302	423

3.4 Impacts of first-generation biofuels on agriculture and food security

This chapter presents the results of an integrated spatial ecological and economic assessment of the impacts of an accelerated biofuel expansion, evaluated in the context of the world food economy and global resource base. The previous sections briefly presented the analysis framework used in this study and the key assumptions regarding economic development and transport energy demand, in particular use of first- and second-generation biofuels. Internally consistent sets of assumptions were formulated as model scenarios and used to quantify impacts of expanding biofuel use on agriculture and world food system outcomes. In total twelve such scenarios were analyzed; the acronyms used and a brief description is given in Table 3.4-1.

3.4.1

Baseline assessment

Before turning to the impacts simulated for different assumptions on biofuel expansion, we briefly summarize results for a baseline without additional biofuel production. For this neutral point of departure, we have selected scenario REF-01 (see Table 3.4-1), i.e. a reference projection of the system where use of agricultural crops as feedstock for biofuel production is frozen at the level recorded in 2008.

Agricultural demand and production

In the long run demand of agriculture is driven by population and economic growth. Over the next two decades world population growth is projected at about 1 percent with most of the increase being in developing countries. While the recent economic growth rates of more 8 percent annually in China and India may have been dented by the recent world financial crisis, relatively robust economic growth in China, India and other middle-income developing countries is expected in the next two decades and this will increase in higher staple food and feed for meat and dairy demand and here cereals are of concern as they will result in direct competition with ethanol production.

Crop production is driven by yield and acreage developments. In many developing countries the crop yields for most commodities are lower than those attained in developed countries. At the global level grain yields increased by an average of some 2 percent annually in the period 1970 to 1990 but since then the rate of yield growth has halved.

With considerable population growth (as derived from the IIASA revised IPCC A2 scenario; see brief description in section 3.2, for details see Riahi et al., 2006) in the reference projections of scenario REF-01 (keeping use of agricultural commodities during 2008-2050 constant at 2008 levels), total production of cereals increases from 2.1 billion tons in 2000 to 3.1 billion tons in 2030, and further to 3.7 billion tons in 2050. While developing countries produced about half the global cereal harvest in 2000, their share in total production increases steadily, reaching 57 percent by 2050. As their share in global consumption increases from 53 percent to 63 percent in this reference projection, net imports of cereals by developing countries are growing over time, from 110 million tons in 2000 to about 210 million tons in 2030, and some 240 million tons by 2050.

Biofuel scenarios analyzed in this study

Table 3.4 - 1

ACRONYM	SCENARIO DESCRIPTION
REF-00	Starting in 1990, assumes a world without any agricultural crops used for biofuel production.
REF-01	Assumes historical biofuel development until 2008; feedstock demand kept constant after 2008; used as a reference run to which alternative biofuel scenarios are compared for their impact.
REF-02	Assumes historical biofuel development until 2008; feedstock demand faded out linearly between 2008 and 2020; used to test a possible alternative future without first-generation biofuel feedstocks beyond 2020.
WEO-V1	Assumes transport energy demand and regional biofuel use as projected by IEA in its WEO 2008 Reference Scenario. Second-generation conversion technologies become commercially available after 2015; deployment is gradual (see Table 3.3-2)
WEO-V2	Assumes transport energy demand and regional biofuel use as projected by IEA in its WEO 2008 Reference Scenario. Assumes that due to delayed arrival of second-generation conversion technologies all biofuel production until 2030 is based on first-generation feedstocks.
WEO-V3	Assumes transport energy demand and regional biofuel use as projected by IEA in its WEO 2008 Reference Scenario. Accelerated development of second-generation conversion technologies permits rapid deployment of second-generation biofuels; consequently, reduced competition with food/feed uses of agricultural crops.
TAR-V1	Assumes transport energy demand as projected by IEA in its WEO 2008 Reference Scenario. Assumes that mandatory, voluntary or indicative targets for biofuel use announced by major developed and developing countries will be implemented by 2020, resulting in about twice the biofuel consumption compared to WEO 2008. Second-generation conversion technologies become commercially available after 2015; deployment is gradual (percentage as inas in WEOV1)
TAR-V2	Assumes transport energy demand as projected by IEA in its WEO 2008 Reference Scenario. Assumes that mandatory, voluntary or indicative targets for biofuel use announced by major developed and developing countries will be implemented by 2020. Assumes that due to delayed arrival of second-generation conversion technologies all biofuel production until 2030 is based on first-generation feedstocks.
TAR-V3	Assumes transport energy demand as projected by IEA in its WEO 2008 Reference Scenario. Assumes that mandatory, voluntary or indicative targets for biofuel use announced by major developed and developing countries will be implemented by 2020. Accelerated development of second-generation conversion technologies permits rapid deployment; 33% and 50% of biofuel use in developed countries from second-generation in 2020 and 2030 respectively.
SNS	Sensitivity scenarios assuming low (V1), intermediate (V2), high (V3), and very high (V4) share of first-generation biofuels in total transport fuels (see Table 3.3-3).

Cereal production and consumption; baseline without biofuel expansion Table 3.4 - 2

REF-01	Cereal production (million tons)				Cereal consumption (million tons)			
	2000	*2020*	*2030*	*2050*	*2000*	*2020*	*2030*	*2050*
North America	478	623	660	713	317	418	437	473
Europe & Russia	530	583	611	664	546	593	622	700
Pacific OECD	40	51	54	60	45	47	49	58
Rest of World	75	100	113	156	99	114	117	121
Africa	75	135	173	299	107	182	236	367
Asia, East	423	536	591	694	458	567	615	702
Asia, South	345	462	519	629	338	486	548	700
Latin America	130	212	249	334	140	197	230	296
Middle East & N.Africa	54	80	93	147	102	170	208	281
Developed	1123	1357	1438	1593	1008	1172	1225	1352
Developing	1027	1424	1624	2104	1145	1603	1837	2345
World	2150	2781	3062	3697	2152	2775	3062	3698

Source: IIASA world food system simulations; scenario REF-01, December 2008.

Agricultural prices in the baseline projection, scenario REF-01 Table 3.4 - 3

Commodity group	Price Index (1990=100)			
	2010	*2020*	*2030*	*2050*
Crops	104	110	120	116
Cereals	118	125	137	133
Other crops	98	103	112	108
Livestock products	109	116	124	134
Agriculture	106	112	121	121

Source: IIASA world food system simulations; scenario REF-01, December 2008.

Agricultural prices

Real prices of agricultural crops declined by a factor of more than two during the period from the late 1970s to the early 1990s and then stagnated until about 2002 when food prices started to rise. The long term trend in declining food prices has been the result of several drivers: population development and slowing demographic growth; technological development, notably substantial increase in productivity since the green revolution in the early 1970s; and support policies maintaining relatively inelastic agricultural supply.

The index of world food prices has increased by some 140 percent during the period 2002 to 2007 primarily a result of increased demand for cereals and oilseeds for biofuels, low world food stocks, reduced harvest in some locations, for example in Australia and Europe due to drought conditions, record oil and fertilizer prices and world market speculation. Estimates indicate that the high food prices seen in 2007/08 resulted in additional 100 million people at risk of hunger. Since the second half of 2008 agricultural prices have again been decreasing substantially.

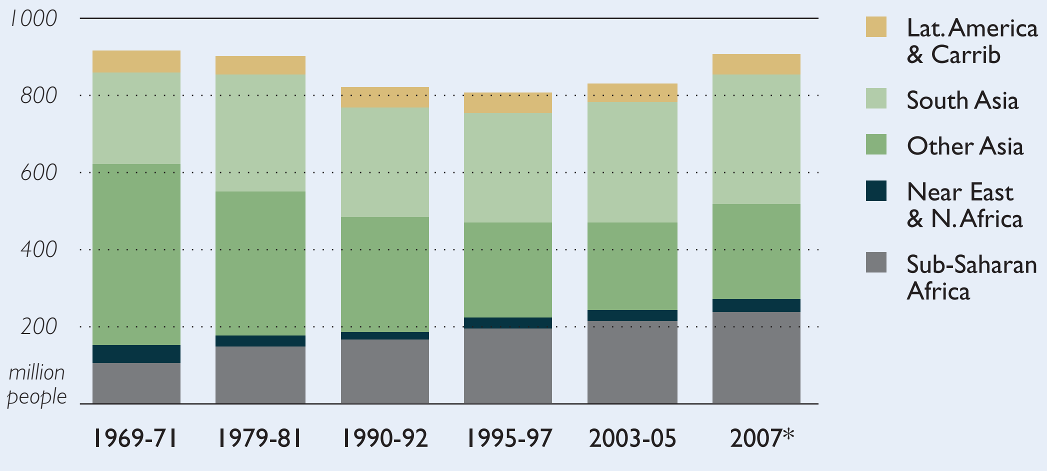
The baseline projection of scenario REF-01 is characterized by modest increases of world market prices during 2000 to 2030. With population growth slowing after 2030, agricultural prices stabilize or even decline slightly. Table 3.4-3 shows projected price indexes for crops and livestock products in comparison to 1990 levels.

Risk of hunger

In 1970, 940 million people in developing countries, a third of population were chronically undernourished. During the next two decades, the number of undernourished people declined by some 120 million to some 815 million in 1990. The largest reduction occurred in East Asia where the number of undernourished people declined from some 500 million in 1970 to about 250 million in 1990. The number of undernourished people increased slightly in South Asia and almost doubled in Sub-Saharan Africa. The total number of undernourished in the developing countries further declined from 815 million in 1990 to 776 million people in 2000. During this same period, the number of undernourished in SSA increased from 168 million to 194 million. Africa has the highest proportion of undernourished people, about 35 percent of the total population compared to about 14 percent of the total population of the rest of the developing world.

The REF-01 scenario projects a globally decreasing number of people at risk of hunger. The projected decrease is most pronounced in East Asia and South Asia. For Africa a further increase in the number of people at risk of hunger is projected, resulting for 2020 in 40 percent of total number of people at risk at

Historical trends in number of undernourished people, developing countries Figure 3.4 - 1



Source: FAO (2008c; 2001).
Note: FAO states the estimate for 2007 is based on partial data for 2006-08 and a simplified methodology and should therefore be regarded as provisional.

People at risk of hunger, baseline projection REF-01 Table 3.4 - 4

REF-01 *Millions*	2000	2010	2020	2030	2050
Africa	198	253	289	319	326
Asia, East	172	142	111	80	35
Asia, South	359	361	303	219	72
Latin America	58	61	55	51	30
Middle East & N. Africa	43	50	49	50	39
Rest of World	53	51	47	46	33
World	884	918	854	765	536

Source: IIASA world food system simulations; scenario REF-01, December 2008.

hunger originating from Africa, and 60 percent in 2030. While achieving some progress in mitigating hunger, the projected development in the scenario REF-01 cannot meet the reductions necessary to achieve this Millennium Development Goal.

Value added of crop and livestock production

In the REF-01 scenario, the global value added of crop and livestock production in 2000 amounted to US1990$ 1260 billion. This is projected to increase by over a third in the 20 year period to 2020. In 2030 and 2050 the value added amounts to US1990$ 1934 and US1990$ 2455 respectively. The developing country share of this value added increases steadily, amounting in 2020, 2030 and 2050 respectively to 66, 68 and 70 percent.

Cultivated land

Some 1.6 billion ha of land are currently used for crop production, with nearly 1 billion ha under cultivation in the developing countries. During the last 30 years the world's crop area expanded by some 5 million ha annually, with Latin America alone accounting for 35 percent of this increase. The potential for arable land expansion exists predominately in South America and Africa where just seven countries account for 70 percent of this potential. There is relatively little scope for arable land expansion in Asia, which is home to some 60 percent of the world's population.

Projected global use of cultivated land in the REF-01 baseline scenario increases by about 200 million ha during 2000 to 2050. While aggregate arable land use in developed countries remains fairly stable, practically all of the net increases occur in developing countries. Africa and South America together account for 85 percent. As these simulations include crop demand for biofuel production up to 2008 (keeping these levels constant thereafter), the results illustrate that some 150 million hectares additional arable land may be required in 2050 to meet food and feed demand alone.

Value added of crop and livestock sector (billion US$ 1990) Table 3.4 - 5

REF-01 *Billion US$ 1990*	2000	2020	2030	2050
North America	168	205	220	239
Europe & Russia	207	237	251	269
Pacific OECD	46	57	64	78
Rest of World	63	80	89	117
Africa	65	107	135	222
Asia, East	249	317	349	414
Asia, South	254	363	423	549
Latin America	155	243	293	395
Middle East & N. Africa	54	87	109	173
Developed	484	579	624	704
Developing	777	1117	1310	1752
World	1262	1696	1934	2455

Source: IIASA world food system simulations; scenario REF-01, December 2008.

Cultivated land (million hectares) Table 3.4 - 6

REF-01 *Million hectares*	2000	2010	2020	2030	2050
North America	234	236	238	241	245
Europe & Russia	339	339	338	337	332
Pacific OECD	57	59	58	60	63
Rest of World	42	41	40	39	37
Africa	225	245	265	287	316
Asia, East	147	146	146	146	145
Asia, South	274	282	289	295	300
Latin America	174	194	213	230	247
Middle East & N. Africa	67	69	70	72	73
Developed	673	675	674	677	678
Developing	887	937	984	1030	1081
World	1560	1612	1658	1707	1759

Source: IIASA world food system simulations; scenario REF-01, December 2008.

3.4.2
Impacts of first-generation biofuel expansion

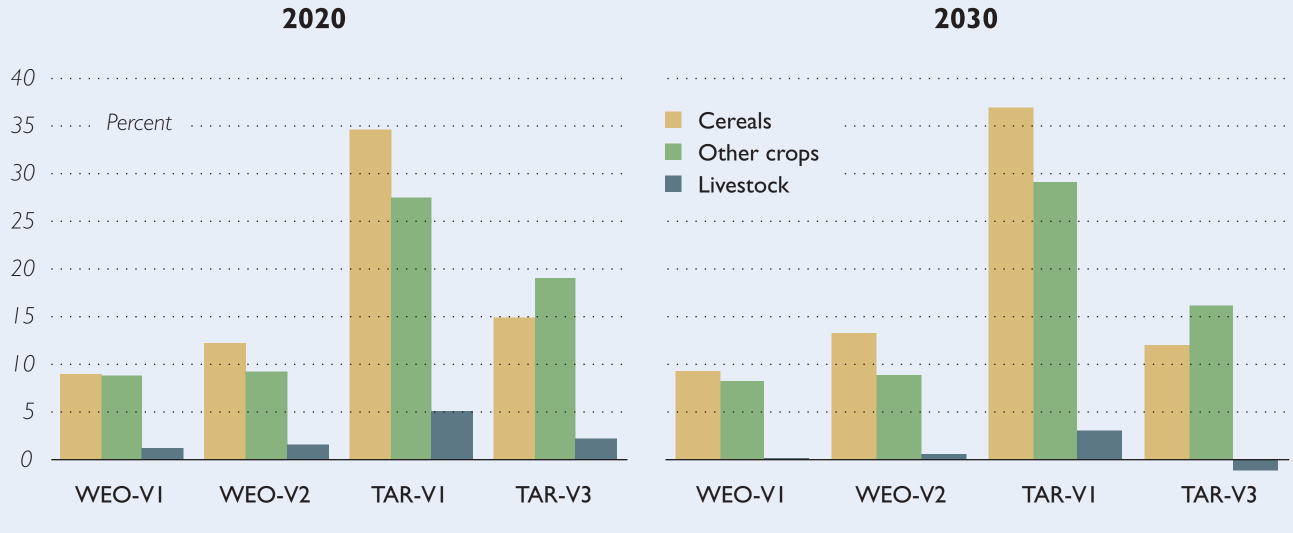
The evaluation of the impacts of additional demand for first-generation biofuels on production, consumption, and trade of agricultural commodities, in particular on food staples, was carried out by comparing the results of a range of biofuel-expansion scenarios to a reference projection of the world food system simulated without imposing additional biofuel demand. The reference projection, termed REF-01, was presented in the previous section. The biofuel-expansion scenarios devised within this study involve several simulation experiments that relate to three aspects:

- Level and time path of transport fuel demand;
- Share of transport energy to be supplied from biofuels;
- Sensitivity of results to development speed of second-generation technologies.

Basic exogenous variables, such as population growth, technical progress and growth of the non-agricultural sector, were left at the levels specified in the reference projection. No specific adjustment policies to counteract altered performance of agriculture have been assumed beyond the farm-level adaptations resulting from economic adjustments of the individual actors in the national models. The adjustment processes taking place in the different scenarios are the outcome of the imposed additional biofuel demand causing changes of agricultural prices in the international national markets; this in turn affects investment allocation and labor migration between sectors as well as reallocation of resources within agriculture. Time is an important aspect in this adjustment process.

Impacts of first-generation biofuels on agricultural prices. Price changes relative to the reference scenario REF-01

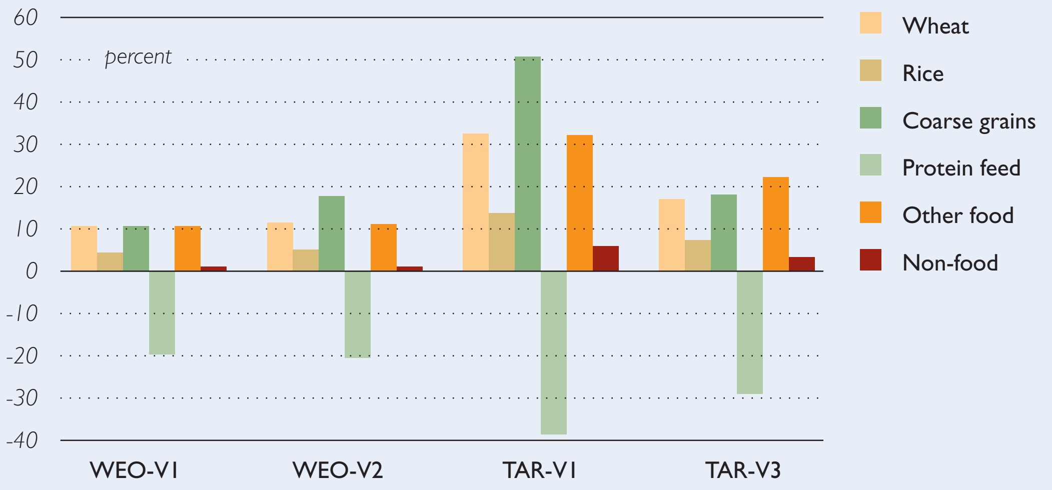
Figure 3.4 - 2



Source: IIASA world food system simulations, December 2008.

Impacts of first-generation biofuels on agricultural prices in 2020

Figure 3.4 - 3



Source: IIASA world food system simulations, December 2008.

Agricultural prices

In a general equilibrium world food system model, when simulating scenarios with increased demand for food staples caused by production of first-generation biofuels, the resulting market imbalances at prevailing prices push international prices upwards.

Figure 3.4-2 shows the results for selected scenarios, namely biofuel demand according to WEO projections in scenario variants WEO-V1 and WEO-V2 (the latter assuming delayed introduction of second-generation technologies) and high biofuel consumption levels according to the TAR scenario in variants TAR-V1 and TAR-V3 (accelerated introduction of second-generation biofuels).

For 2020, the price increases for both cereals and other crops under the WEO scenario are in the order of 10 percent. As the contribution of second-generation biofuels is still small in WEO-V1, the further delay assumed in WEO-V2 causes only moderate further crop price increases. For biofuel demand specified in the TAR scenario (i.e. about twice the level projected in the WEO scenario) the impact on crop prices in 2020 is fairly substantial, of the order of 30 percent. With accelerated introduction of cellulosic ethanol, as assumed in TAR-V3, the price impact on cereals would be halved to about 15 percent. Due to high targets in developing countries, with a higher share of biodiesel and somewhat slower deployment of second-generation technologies, the impact on non-cereal crops (in particular vegetable oils) is stronger than simulated for cereals.

For 2030 the pattern of price impacts remains similar to 2020. As second-generation biofuels gain importance towards 2030, the differences in price impacts between WEO-V1 and WEO-V2 variants become more visible. With accelerated deployment of second-generation fuels even the large volumes of biofuels produced in TAR-V3 can be achieved with price increases in the range of 10-15 percent.

Price impacts simulated for different crop sectors and scenario variants in 2020 are shown in Figure 3.4-3. The results highlight that the largest price increase is computed for coarse grains (due to maize-based ethanol production). The large negative price impact on protein feeds (shown in blue) is caused by biofuel by-products entering the market in large volumes (e.g. livestock feed from starch-based ethanol production; protein meals and cakes from crushing of oilseeds). Having access to cheaper feed sources also results in only modest increases of livestock product prices (see Figure 3.4-2).

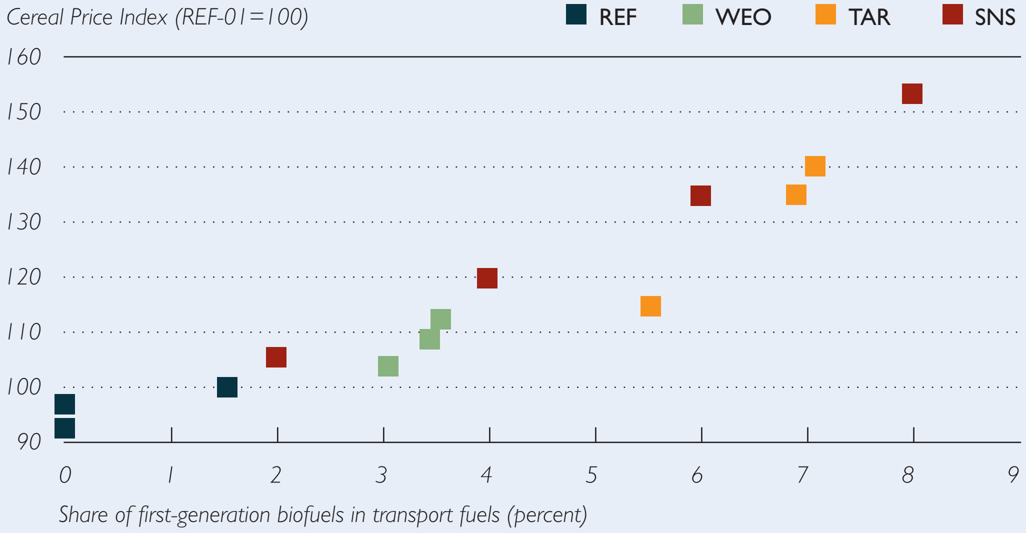
Summarizing over all scenario experiments, we find that agricultural prices considerably depend on the aggregate share that first-generation biofuels are mandated to contribute to total transport fuel consumption. This is shown in Figure 3.4-4.

Cereal demand and production

The rising agricultural prices in the biofuel scenarios provide incentives on the supply side, for intensifying production and for augmenting and reallocating land, capital and labor. At the same time, consumers react to price increases and adjust their patterns of consumption. Figure 3.4-5 shows the producer response of cereal sectors for different biofuel scenarios in 2020 and 2030, i.e. the amount of additional cereal production realized in each scenario.

The additional global use of cereal commodities for ethanol production relative to the reference simulation REF-01 is around 100 million tons in WEO-V1 and WEO-V2, 240 million tons in TAR-V3 and 330 million tons in scenario TAR-V1. Figure 3.4-5 highlights that production increases in response to higher agricultural prices are stronger in developed countries, as are the reductions in feed use (see Figure 3.4-6). When it comes to food use, however, consumption in developed countries is much less responsive than in developing countries, which account for 75 percent of the 'forced' reduction in cereal food consumption.

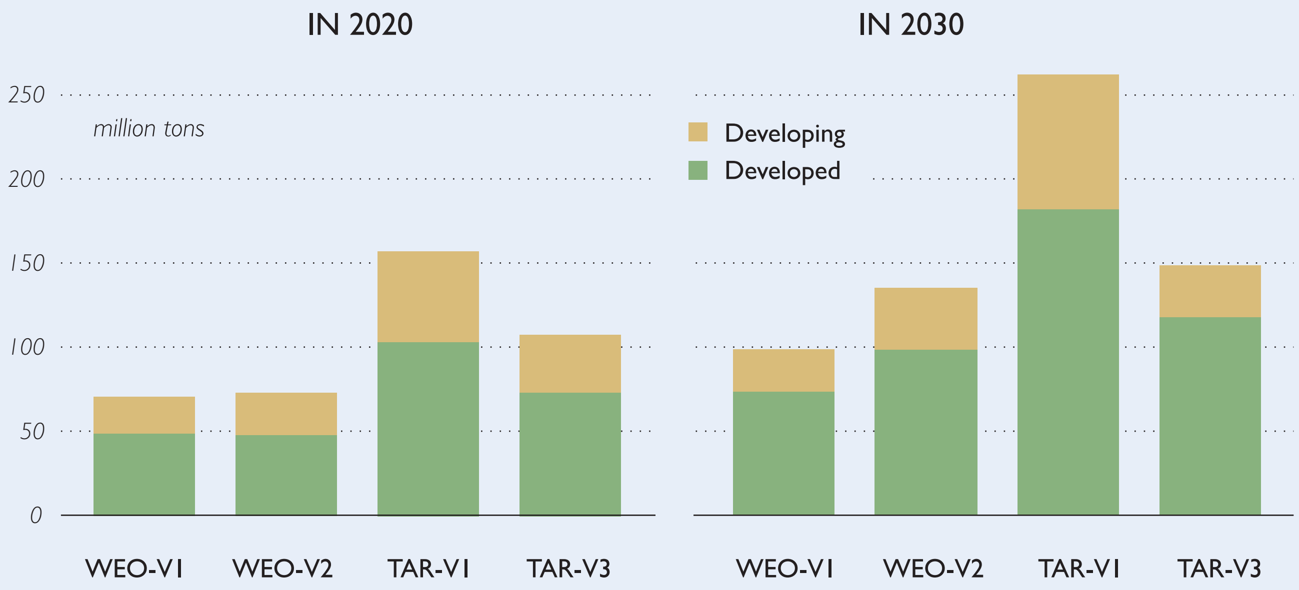
Cereal price index versus share of first-generation biofuels in transport fuels, in 2020 Figure 3.4 - 4



Source: IIASA world food system simulations, December 2008. Note: SNS = sensitivity scenarios; TAR = scenario simulations based on mandates and indicative voluntary targets; WEO = simulations based on WEO 2008 projections of biofuel demand; REF = reference projections with constant, decreasing or no biofuel demand beyond 2008).

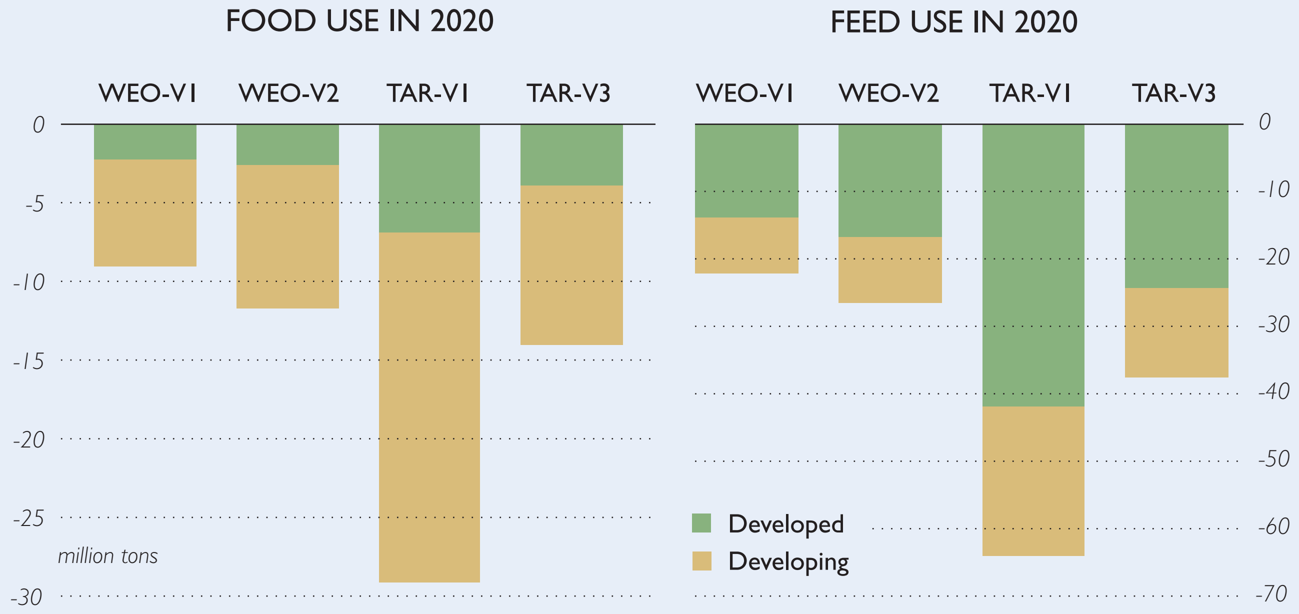
Change in cereal production relative to baseline REF-01, in 2020

Figure 3.4 - 5



Change of cereal use relative to baseline REF-01, in 2020

Figure 3.4 - 6

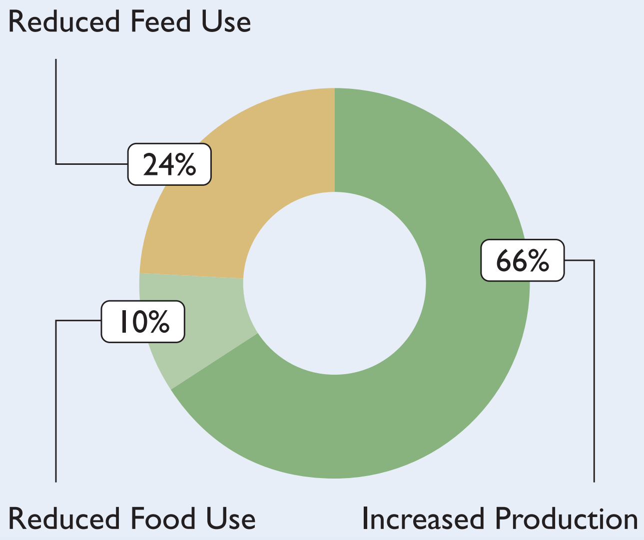


Where do the cereals needed for biofuel production come from?

Box 3.4 - 1

On average about two-thirds of the cereals used for ethanol production are obtained from additional crop produktion.

The remaining ohne third comes fom consumtion changes. The reduction in direct cereal food consumption accounts for ten percent of the amount of cereals used for biofuel production, reduced feed use accounts for about a quarter.



Rising food commodity prices tend to negatively affect lower income consumers more than higher income consumers. First, lower income consumers spend a larger share of their income on food and second, staple food commodities such as corn, wheat, rice, and soybeans account for a larger share of food expenditures. Responses on the consumer side, reduced food and feed use of cereals, are shown in Figure 3.4-6.

Figure 3.4-7 summarizes for 2020 and 2030 the level of global cereal production (left panel) and of global cereal food consumption (right panel) across all simulated biofuel scenarios. The horizontal axis indicates the percentage of first-generation biofuels[45] in total transport fuels associated with a particular scenario experiment. In 2020 the range of scenarios results in a cereal production of 2.7 to 3.0 billion tons and in 2030 of 3.0 to 3.4 billion tons.

Risk of hunger

The estimated number of people at risk of hunger used in the world food system model is based on FAO data (FAO, 2001b; 2008b) and relies on a strong empirical correlation between the share of undernourished in a country's total population and the ratio of average per capita dietary food supply relative to average national per capita food requirements. Historical trends in undernourished people were discussed earlier and shown in Figure 3.4-1.

The model results show that an ambitious biofuel target for 2020, as specified in the TAR scenario, causes higher prices if achieved mainly by production of first-generation biofuels. Consequently this reduces food consumption in developing countries, which in turn results in increased number of people at risk of hunger. Figure 3.4-8 shows a comparison of results until 2030 for the baseline scenario REF-01 (biofuel demand fixed at 2008 level) versus estimated number of

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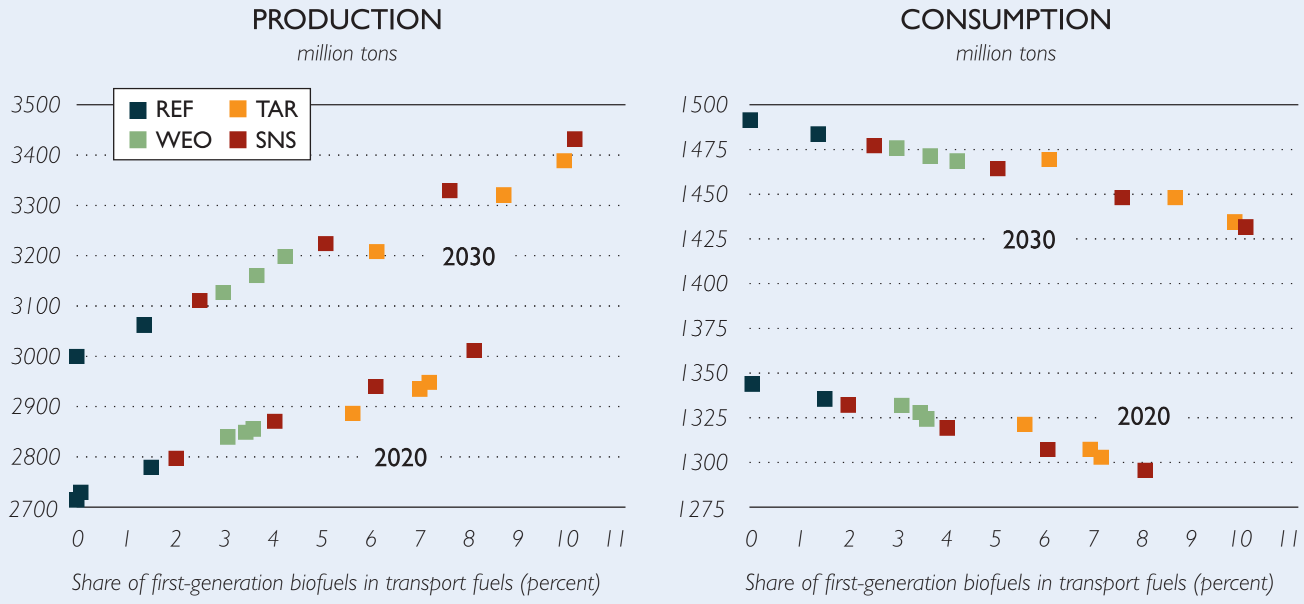
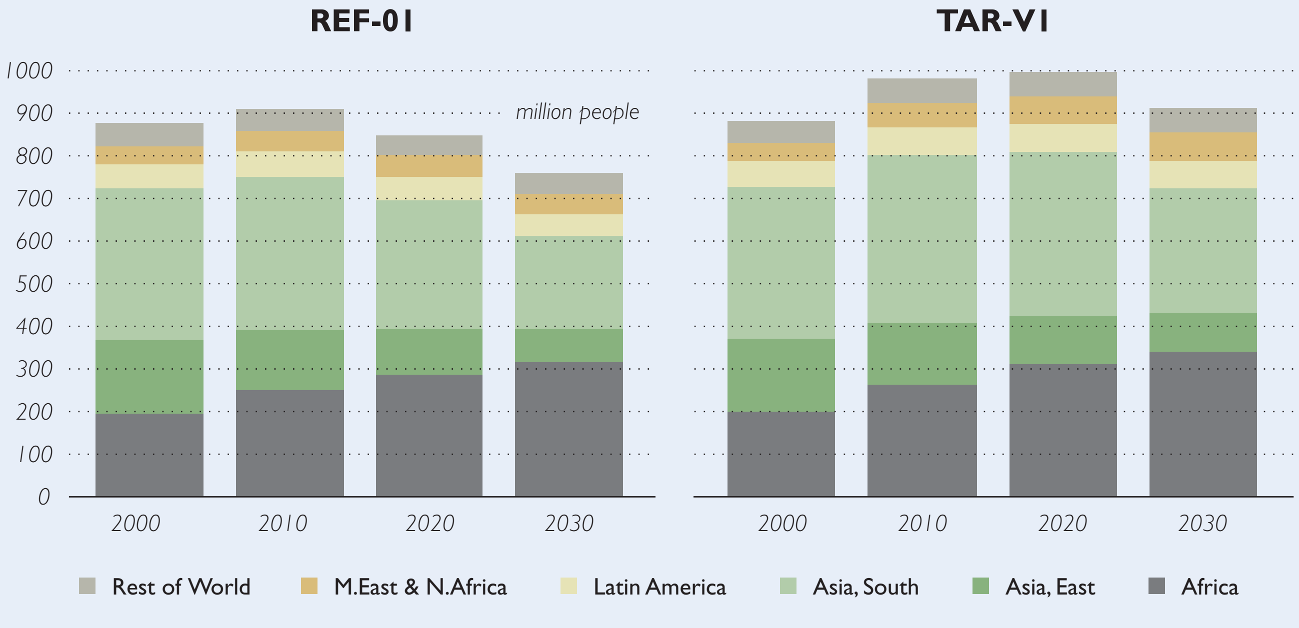
[45] This share is achieved by a variety of feedstocks including cereals, sugar crops, and cassava to produce first-generation ethanol and various oilseeds and oil crops to produce biodiesel.

Cereals versus share of first-generation biofuels in transport fuels Figure 3.4 - 7

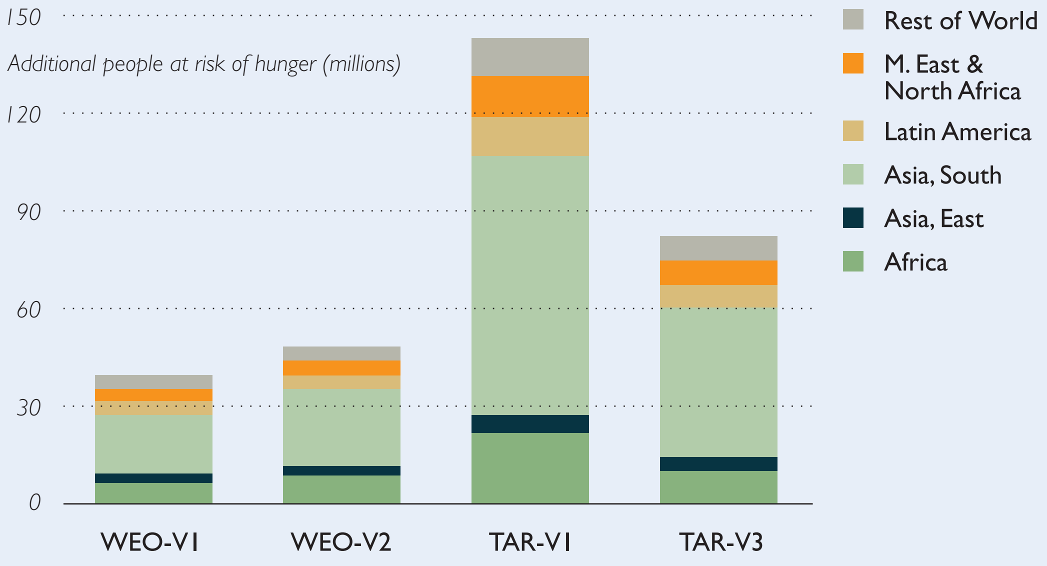


Risk of hunger in REF-01 and TAR-V1 scenarios Figure 3.4 - 8



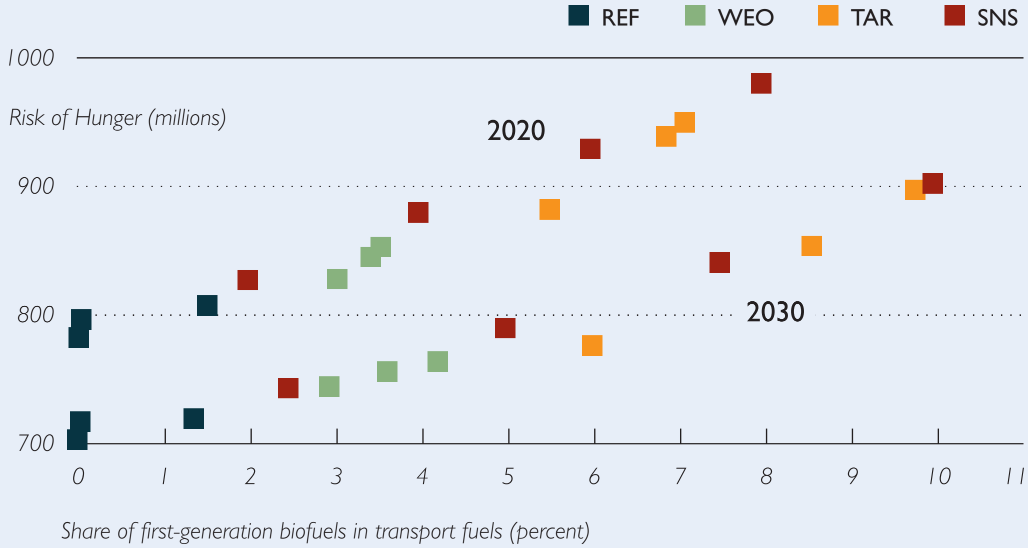
Additional people at risk of hunger relative to baseline REF-01, in 2020

Figure 3.4 - 9



People at risk of hunger versus share of first-generation biofuels in total transport fuels

Figure 3.4 - 10



people at risk of hunger in the TAR-V1 scenario, i.e. when implementing an ambitious global biofuel target with only gradual introduction of second-generation technologies, mainly after 2020.

While in the reference scenario REF-01 the number of undernourished people peaks in 2009-10 at somewhat more than 900 million and then declines (estimated 850 million in 2020 and 765 million in 2030), this indicator continues to increase in the TAR-V1 scenario until 2020 to reach 1 billion and only then starts to decline as second-generation production begins to take pressure off the competing food-feed-biofuel feedstock markets.

Figure 3.4-9 presents the simulated regional distribution of additional undernourished in different biofuel scenarios, showing a large impact in particular in South Asia. It is worth noting that even with relatively swift deployment of second-generation technologies, as assumed in scenario TAR-V3, the results for 2020 show an increase of 80 million undernourished people.

The reference scenario without biofuels project for developing countries the number of undernourished people in 2020 and 2030 at respectively to 807 and 720 million. The biofuels target scenario estimates for developing countries that an additional 131 and 136 million people will be at risk of hunger in 2020 and in 2030 respectively. In the biofuels target scenario with accelerated second-generation biofuels, the corresponding number of additional people at risk of hunger decreases to 75 million and 57 million respectively in 2020 and 2030. Africa and South Asia account for two-thirds to three-quarters of the additional population at risk of hunger in developing countries across biofuels scenarios in 2020 as well as in 2030.

Figure 3.4-10 summarizes results for developing countries obtained across all biofuel scenarios. It is worth noting that for the range of simulated global shares of first-generation biofuels in total transport fuels of 0 to 8 percent in 2020 and of 0 to 10 percent in 2030, the resulting impact on number of people at risk of hunger is substantial, up to about 200 million, for both time points, albeit with the total numbers higher in 2020 by about 100 million.

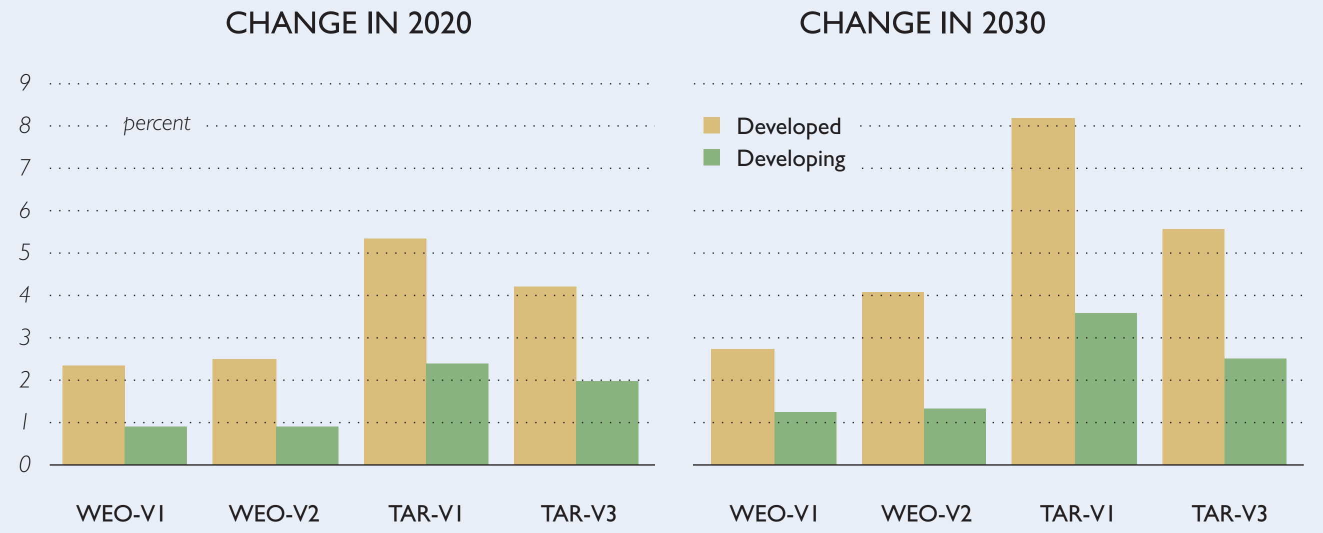
The Millennium Development Goals put a time bound target to reduce world hunger by half in the period to 2015 and it is estimated that this would require public funding of some US$ 50 to 80 billion annually. Putting this in perspective, the OECD agricultural subsidy budget amounts to over US$ 300 billion annually.

Value added of crop and livestock production

Biofuel development has been seen as a means to diversify agricultural production and – especially in developed economies – has shaped agricultural support policies. The study has considered as to what extent the additional production of crops developed on arable land as feedstock for biofuels production will increase value added in agriculture. The percentage change relative to the reference scenario REF-01, with biofuels kept constant at the level of 2008, is shown in Figure 3.4-11.

Figure 3.4-11 shows that for all biofuels scenarios agricultural value added increases at the global and regional levels, as indeed expected. For instance for scenario WEO-V1 (with relatively modest biofuels development), the changes in absolute terms amount to US1990$ 24 billion in 2020, 33 billion in 2030 and 53 billion in 2050. The developed countries account initially for about 55-60 percent of the global gain in agriculture value added. As their relative weight in global agriculture decreases over time, so does their share in global gains, amounting to just over 50 percent in 2030, and on average 45 percent of the estimated gains in 2050. The figure also shows that agricultural sectors in developed countries benefit relatively more than in developing countries in terms of percentage

Change in agricultural value added relative to baseline REF-01 Figure 3.4-11



gain relative to the baseline. In scenario WEO-V1 the increase in 2020 recorded for developed countries is 2.3 percent compared to only about 1 percent for developing countries. While Africa and Latin America achieve gains of about 1.3 percent, the gains achieved for the Middle East & North Africa region and for Asian regions is only 0.6 to 0.9 percent.

In scenario TAR-V1, with a high demand for first-generation biofuels due to ambitious national targets and only gradual introduction of second-generation technologies, crop and agriculture value added increases substantially, globally by some 3.5 percent. Global agricultural value added is higher by 58 billion US1990$ in 2020, 98 billion in 2030, and 113 billion in 2050. As for scenario WEO-V1, the percentage gains in scenario TAR-V1 are higher for developed countries (about 5.4 percent in 2020) compared to developing regions (average 2.4 percent increase in 2020) where estimated gains fall in a range of 1.2 to 3.7 percent. The biofuels target scenario TAR-V1 shows that the increase in agriculture value added (measured in constant 1990 US$) as a result of biofuels development is projected at US$ 31 billion and US$ 51 billion in the developed countries in 2020 and 2030 respectively. The corresponding values for the developing countries are US$ 27 billion and US$ 41 billion respectively.

3.5 Impacts of first-generation biofuels development on the environment

Apart from key energy security and rural development goals, all national biofuel development initiatives acknowledge climate change mitigation as an important objective and the use of biofuels is expected to reduce greenhouse gas emissions. It is also important that biofuel production takes place on a sustainable basis.

In this section we summarize results obtained for several key indicators of agricultural environmental impacts. These include the magnitude of biofuel induced direct and indirect land use changes and the increased use of agricultural inputs, especially fertilizer. Concerning greenhouse gas emissions, for each scenario we computed the balance of additional greenhouse gas emissions caused by the expanding use of agricultural crops for biofuel production and taking into account the emissions from associated direct and indirect land use changes, feedstock conversion to biofuels, and biofuel distribution, against the greenhouse gas savings resulting from substitution of fossil fuels with biofuels.

Impacts on the use of cultivated land

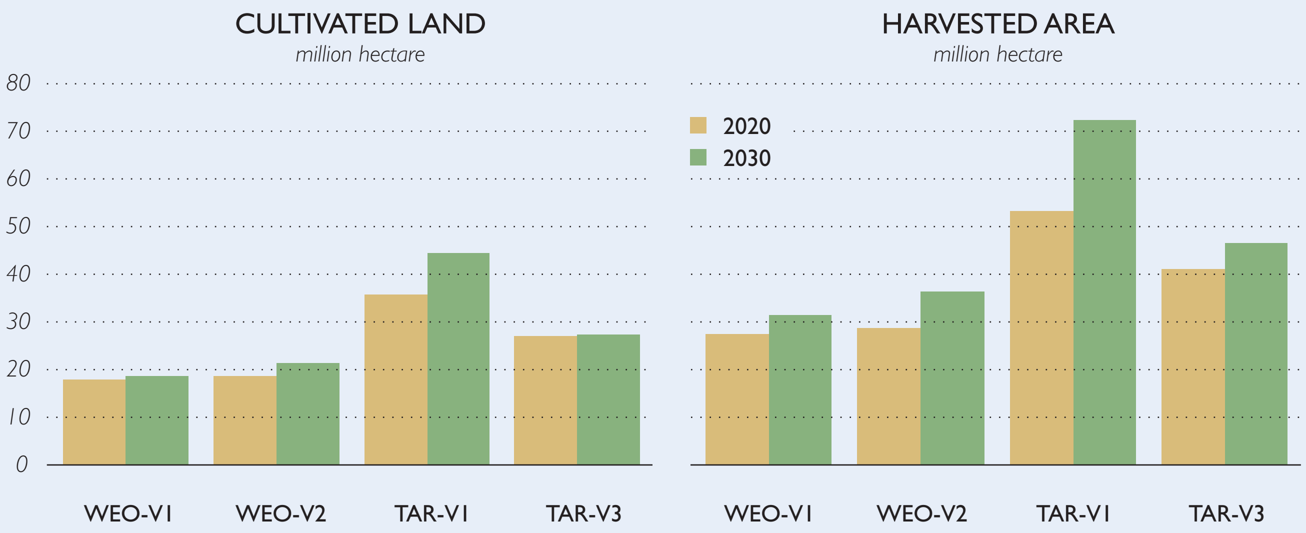
The discussion of the magnitude of land required and the impacts on arable land caused by expanding biofuel production distinguishes two elements: first, direct land use changes, i.e. estimating the extent of land that is used for producing biofuel feedstocks; secondly, the estimation of indirect land use effects, which can result from bioenergy production displacing services or commodities (food, fodder, fiber products) on arable land currently in production.

The approach pursued in this study is to apply a general equilibrium framework that can capture both direct and indirect land use changes by modeling responses of consumers and producers to price changes induced by introducing competition with biofuel feedstock production. This approach accounts for land use changes but also considers production intensification on existing agricultural land as well as consumer responses to changing availability and prices of agricultural commodities.

In a baseline projection without any use of agricultural feedstocks for biofuel production, as portrayed in scenario REF-00, the expansion of arable land to meet growing food and feed requirements during 2000 to 2020 amounts to about 90 million hectares of additional land put into cultivation. Africa and Latin America, with a projected increase of cultivated land of respectively 39 million and 36 million hectares, account for more than 80 percent of total net arable land expansion.

The left panel of Figure 3.5-1, shows the *additional* use of cultivated land in 2020 and 2030 in comparison to a scenario without any crop-based biofuels. For the WEO and TAR biofuel scenarios shown this additional use falls in the range of 18 million hectare (scenario WEO-V1) to 36 million hectares (scenario TAR-V1). For developed countries the arable land use increases in different biofuel scenarios during 2000-2020 in the range of 5 to 13 million hectares, compared to a net decrease by 1 million hectares in a scenario without biofuels. Developing countries record in the baseline without biofuels (scenario REF-00) an increase of arable land use during 2000-2020 that amounts to 92 million hectares; additional crop demand due to biofuel development results in expansion of cultivated land use of 103 to 114 million hectares. The difference of 22 million hectares arable land use in developing countries in scenario TAR-V1 (compared to the results without biofuel demand) is mainly explained by an expansion of 8 million hectares

Additional use of cultivated land and harvested area in 2020 and 2030 Figure 3.5-1



in sub-Saharan Africa and 10 million hectares in South America.

When looking at differences in expansion of cultivated land for the period 2000 to 2030, then the range of estimates for biofuel scenarios relative to the baseline (without biofuels) widens further, from an additional use of 19 million hectares (scenario WEO-V1) to 44 million hectares (scenario TAR-V1).

The right panel of Figure 3.5-1, shows the *additional* harvested area in 2020 and 2030 in comparison to a scenario without any crop-based biofuels. Increase of harvested area includes both the expansion of cultivated land as well as increased multi-cropping, i.e. the intensification of cropping in existing cultivated land. For the WEO and TAR biofuel scenarios shown this additional harvested area falls in the range of 27 million hectare (scenario WEO-V1) to 53 million hectares (scenario TAR-V1). In developed countries the harvested area increases in different biofuel scenarios by 10 to 18 million hectares, in developing by 17 to 35 million hectares. While Africa and South America accounted for more than 80 percent of physical land expansion (i.e. additional cultivated land) their combined share in additional harvested area is only about 45 percent, which indicates that higher agricultural prices lead to a substantial increase in cropping also in regions with limited land resources.

Figure 3.5-2 shows the results obtained for cultivated land use in 2020 and 2030 in relation to the amount of first-generation biofuel production demanded, expressed here as percentage in total transport fuel consumption. For the full range of simulated scenarios the use of cultivated land in 2020 goes from 1649 million hectares to 1694 million hectares, a difference of 45 million hectares, and in 2030 it ranges from 1700 million hectares to 1755 million hectares, i.e. a maximum additional use of 55 million hectares.

In summary, while total global arable land use increases by only 1-3 percent in different biofuel scenarios compared to a situation without biofuels - a number that may seem small at first sight – the impact becomes substantial when expressed in terms of net cultivated land expansion during respectively

2000-2020 and 2000-2030. From this perspective, the impact of biofuel scenarios is to increase the net expansion of cultivated land during 2000-2020 by 20-40 percent, and by 15-30 percent during 2000-2030.

Land cover changes ('deforestation')

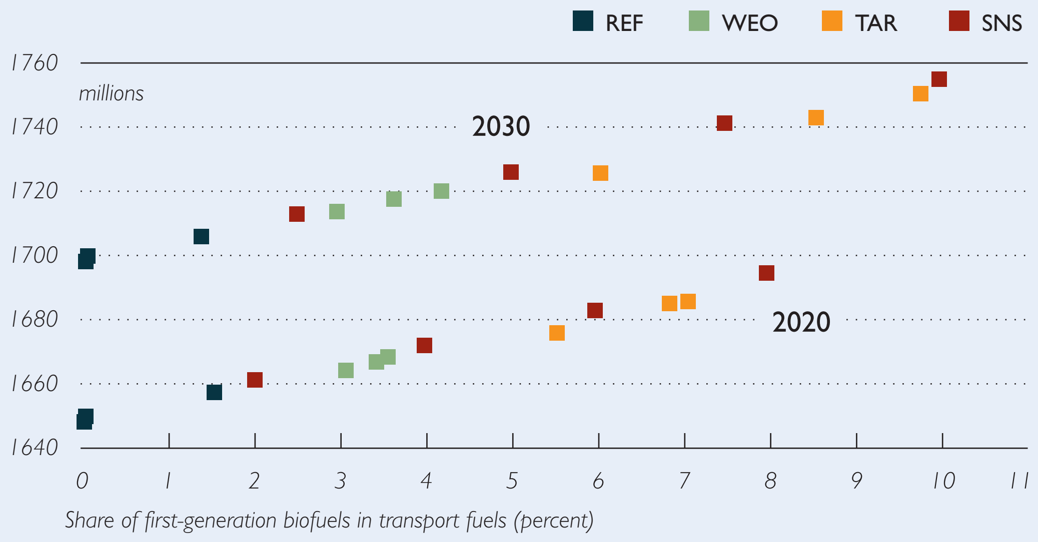
Forests play an important environmental role in the production of timber, wood, fuel, and other products, in the conservation of biodiversity and wildlife habitats, as well as in the mitigation of global climate change and the protection of watersheds against soil degradation and flood risks. About 30 percent of the world's land surface – nearly 4 billion ha – is under forest ecosystems. Eight countries – Russia, Brazil, Canada, the United States, China, Australia, Congo, and Indonesia – account for 60 percent of the world's forest resources. During the past decade, some 127 million ha of forests were cleared, while some 36 million ha were replanted. Africa lost about 53 million ha of forest during this period – primarily from expansion of crop cultivation.

The quantification of land cover changes associated with agricultural development relies on a rule-based downscaling methodology to allocate the results of the world food system simulations to the spatial grid of the resource database for the analysis and quantification of environmental implications.

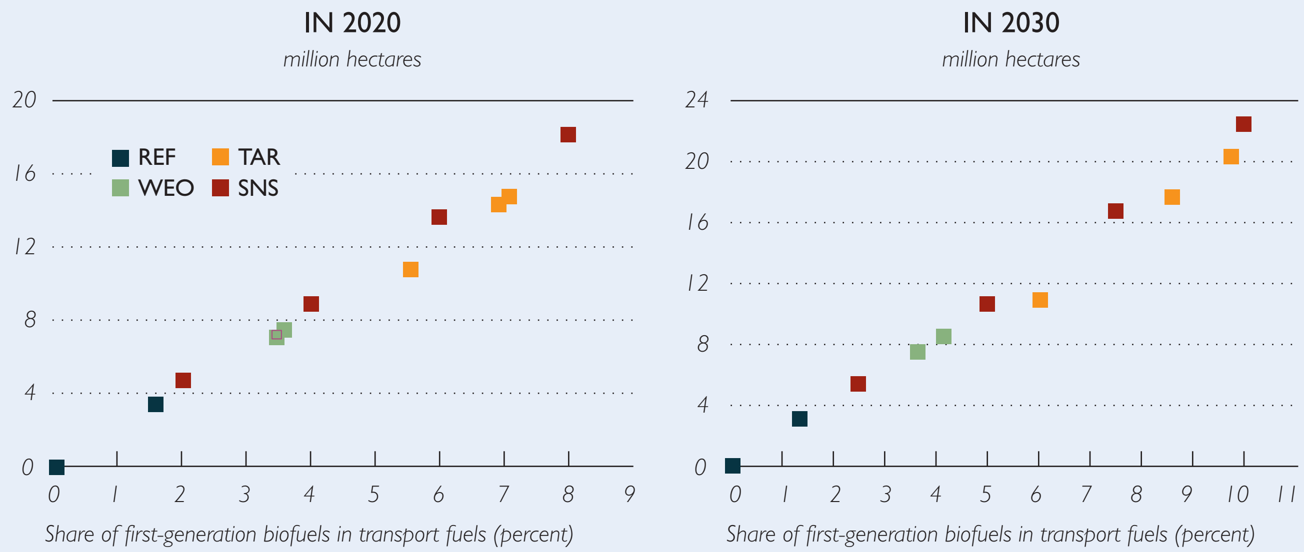
Land cover interpretations have been used for the base year 2000 together with statistical data from the FAO to derive a consistent spatial characterization of each land unit (at 5 by 5 latitude/longitude grid-cells) interms of area shares for seven main land use/land cover classes. These shares are: cultivated land, subdivided into (i) rain-fed and (ii) irrigated land, (iii) forest, (iv) pasture and other vegetation, (v) barren and very sparsely vegetated land, (vi) water, and (vii) urban land and land required for housing and infrastructure.

The downscaling algorithm operates in 10-year steps. For each 10-year period, we solve a series of multi-criteria problems for each country or region of the food system model in order to determine spatial land conversion

Cultivated land use versus share of first-generation biofuels in transport fuels Figure 3.5 - 2



Additional deforestation versus share of first-generation biofuels in transport fuels Figure 3.5 - 3



subject to various constraints, which include: (i) net land conversion as simulated in general equilibrium food system model; (ii) spatially detailed resource availability; (iii) suitability of land for cropping; (iv) legal land use limitations (i.e. protected areas); (v) ecosystem conversion suitability/propensity, and (vi) land accessibility, i.e. proximity to current agricultural activities.

The resulting spatial data sets for each biofuel scenario can then be tabulated and compared to the spatially projected land use in a baseline scenario without biofuel production. By summing up land conversions in different scenarios, converting from forest to cultivated land use, we estimate the amount of additional deforestation directly or indirectly caused by biofuel feedstock production. A summary for 2020 and 2030 across all scenarios is provided in Figure 3.5-3.

Results for 2020 across all scenarios (see left panel) indicate that biofuel feedstock use may be responsible for up to 20 million hectares of *additional* deforestation, i.e. on average 1 million hectare additional forest conversion per year during 2000-2020. The right panel shows results for 2030, with total *additional* forest conversion of up to 24 million hectares due to biofuel feedstock use. This compares to an estimated total forest conversion due to arable land expansion computed for a baseline scenario without biofuels in 2000-2020 amounting to 51 million hectares, and to 80 million hectares by 2030.

The historical rate of deforestation in the 1990s and beginning of this century was estimated by FAO at 8-9 million hectares annually of which Africa and Latin America have contributed about 4 million hectares each (FAO, 2005). Estimates of deforestation are uncertain and causes of deforestation are manifold. There are important factors other than crop agriculture that drive forest conversion. For instance, according to remote sensing data by the National Institute of Space Research (INPE), about two-thirds of the area deforested in Brazil during 2000-2005 was converted to pastures for cattle ranging, around one-third resulted from colonization and associated subsistence farming (for details and data on Brazilian deforestation see http://www. mongabay.com/brazil.html).

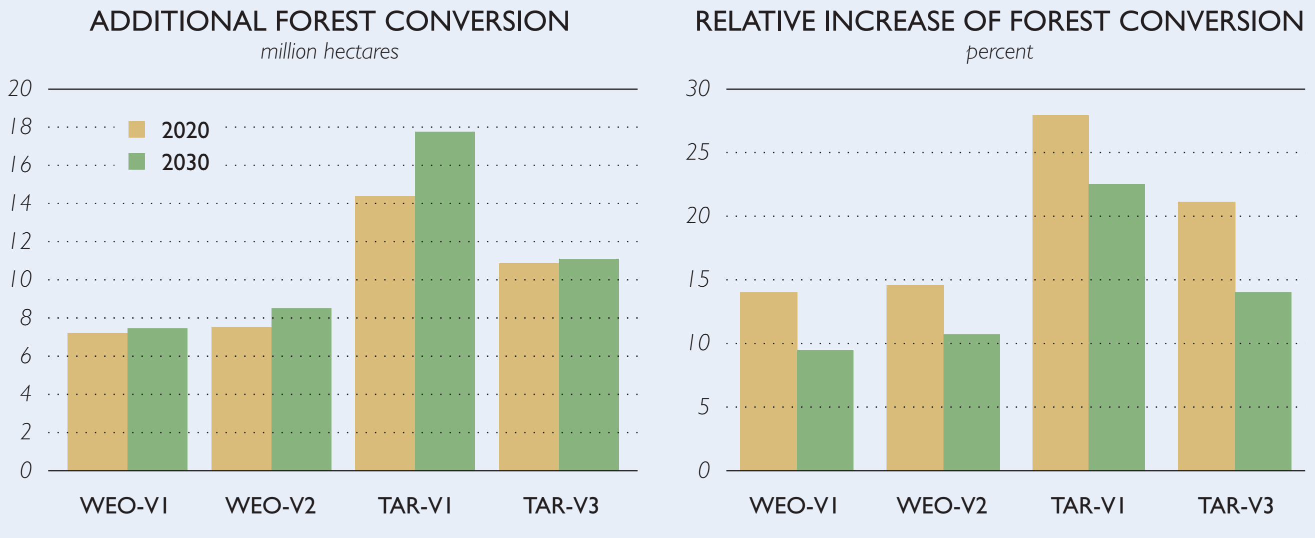
While future forest conversion will depend on the willingness and priorities of national governments to protect forests and the effectiveness of measures taken and incentives provided to reduce deforestation, the analysis of biofuels development scenarios suggests that any prolonged dependence on first-generation crops for biofuels will result in increased risk of deforestation with the inherent consequences of substantial carbon emissions and biodiversity loss. High mandated future demand for first-generation biofuels could trigger substantial additional forest conversion in both Africa and South America.

The level of additional forest conversion obtained for selected biofuel scenarios is shown in Figure 3.5-4. The left panel shows the *additional* forest conversion recorded in selected biofuels scenarios during 2000-2020 and 2000-2030 relative to a reference scenario without considering biofuels demand. The right panel indicates the percentage increase of converted forest areas for the same period. Deforested areas in scenario WEO-V1 (moderate biofuel demand and gradual introduction of second-generation technologies) increase during 2000-2020 by 14 percent more than in the baseline. The largest impact occurs in scenario TAR-V1 as the fast expanding demand for first-generation biofuels increases forest conversion by a quarter.

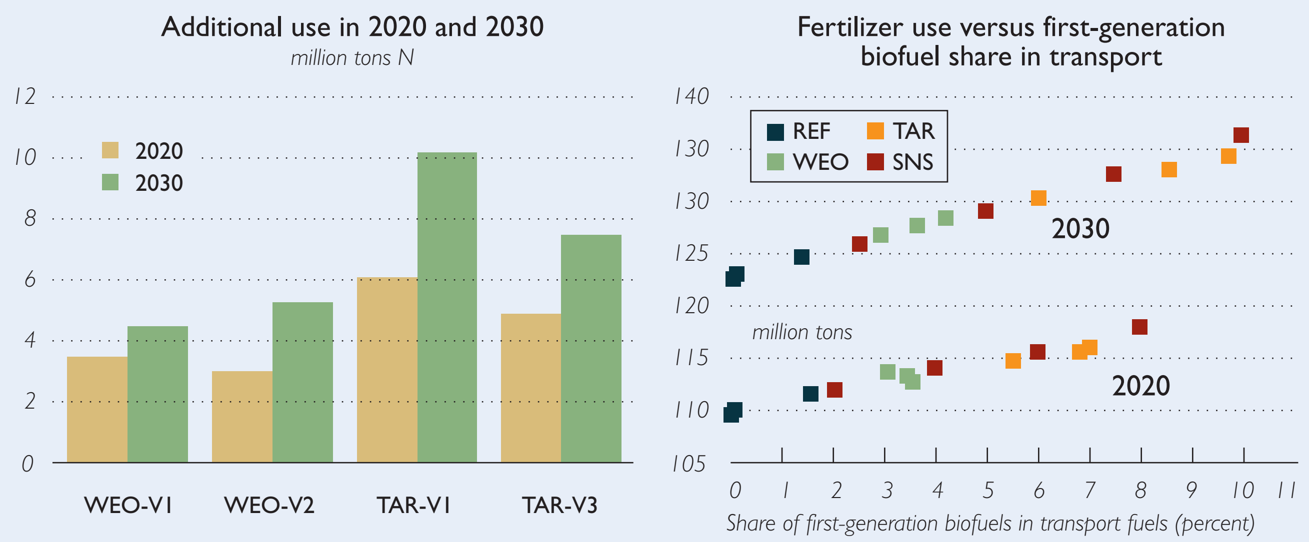
Impact on fertilizer use

As pointed out previously, there are three elements how agricultural supply responds to increasing demand for first-generation biofuel feedstocks: (i) expansion of cultivated land beyond baseline levels; (ii) reallocation of agricultural resources to producing commodities most profitable due to relative price gains, and (iii) intensifying production per unit of cultivated land by increasing multi-cropping and possibly reducing fallow periods (i.e., increasing the ratio of harvested area to cultivated

Additional forest conversion in different biofuel scenarios Figure 3.5 - 4



Nitrogen fertilizer use in biofuel scenarios Figure 3.5 - 5



land) and by increasing agricultural inputs such as fertilizers, the quality of seeds or irrigation.

For the biofuel scenarios analyzed in this study we obtain results on changes in the amount of nitrogenous fertilizers applied in response to a range of assumed levels of first-generation biofuel feedstock demand. A summary of additional use of nitrogen fertilizer for WEO and TAR scenarios (left panel) and the overall response of fertilizer use across all scenarios (right panel) is displayed in Figure 3.5-5.

Nitrogen fertilizer use in the baseline projection increases by 40 million tons in the period of 2000 to 2030 (up from 83 million tons in 2000). High levels of mandated first-generation biofuel feedstock demand could add to this another 10 million tons (scenario TAR-V1), i.e. a 25 percent increase over projected growth of nitrogen fertilizer use in a baseline without demand for first-generation biofuel feedstocks. As a consequence, about 8 percent more nitrogen fertilizers would be applied in 2030 compared to the baseline.

Impacts on greenhouse gas savings

The main issues and arguments surrounding the debate about the greenhouse gas effectiveness of biofuels were discussed in chapter 2.5. In short, biofuels are produced from biomass and the CO_2 released through their combustion matches the amount of carbon absorbed by the plants from the atmosphere through photosynthesis; hence they appear to be carbon-neutral. However, greenhouse gases are emitted at all stages, from ‘cradle to grave’ of the biofuels production and uses chain in the production and transportation of feedstocks, during conversion to biofuels, distribution to end user, and in final use.

Greenhouse gases can also be emitted or sequestered as a consequence of direct or indirect land-use changes when natural habitats or previously unused or differently used land is converted to production of biofuel feedstocks. Of particular concern for greenhouse gas impacts is conversion of forests or plowing of carbon-rich soils. Furthermore, biofuel feedstock production may not directly cause problematic conversions but may displace food or feed production to environmentally sensitive areas. Carbon debts and greenhouse gas impacts associated with biofuel production are much debated and due to the complexity of the involved land use and technical conversion systems they are difficult to quantify.

In this study we apply a general equilibrium approach to capture indirect land use changes by modeling responses of consumers and producers to price changes induced by the competition of biofuel feedstock production with food and feed production. This approach not only takes into account land use changes but also considers production intensification on existing agricultural land as well as consumer responses to changing prices and availability of commodities.

For the quantification of greenhouse gas savings due to biofuel use (assuming this use will substitute for fossil transport fuels) we apply various estimates from the literature (FAO, 2008a; Fritsche & Wiegmann, 2008; Commission of the European Communities, 2008). Estimated greenhouse savings are specific to different feedstock plants; coefficients used vary from 15-40 percent savings for maize to 70-95 percent savings for ethanol produced from sugar cane (for details, see chapter 2.5.2).

The impact of first-generation biofuel production on land use has been quantified by comparing land use development of a particular biofuel scenario with the land use resulting in a scenario without biofuel use. Note that this comparison includes both direct and indirect land use changes. The study methodology projects spatially explicit agricultural land uses. A carbon accounting method, based on IPCC Tier 1 approaches (IPCC, 2006), was used to quantify vegetation and soil carbon pools for each scenario. While this method is consistent with the recommended approach for greenhouse gas inventories, it goes without saying that there are large uncertainties involved in estimating regional and global carbon pools. The results should be seen as indicative for the direction and magnitude of changes.

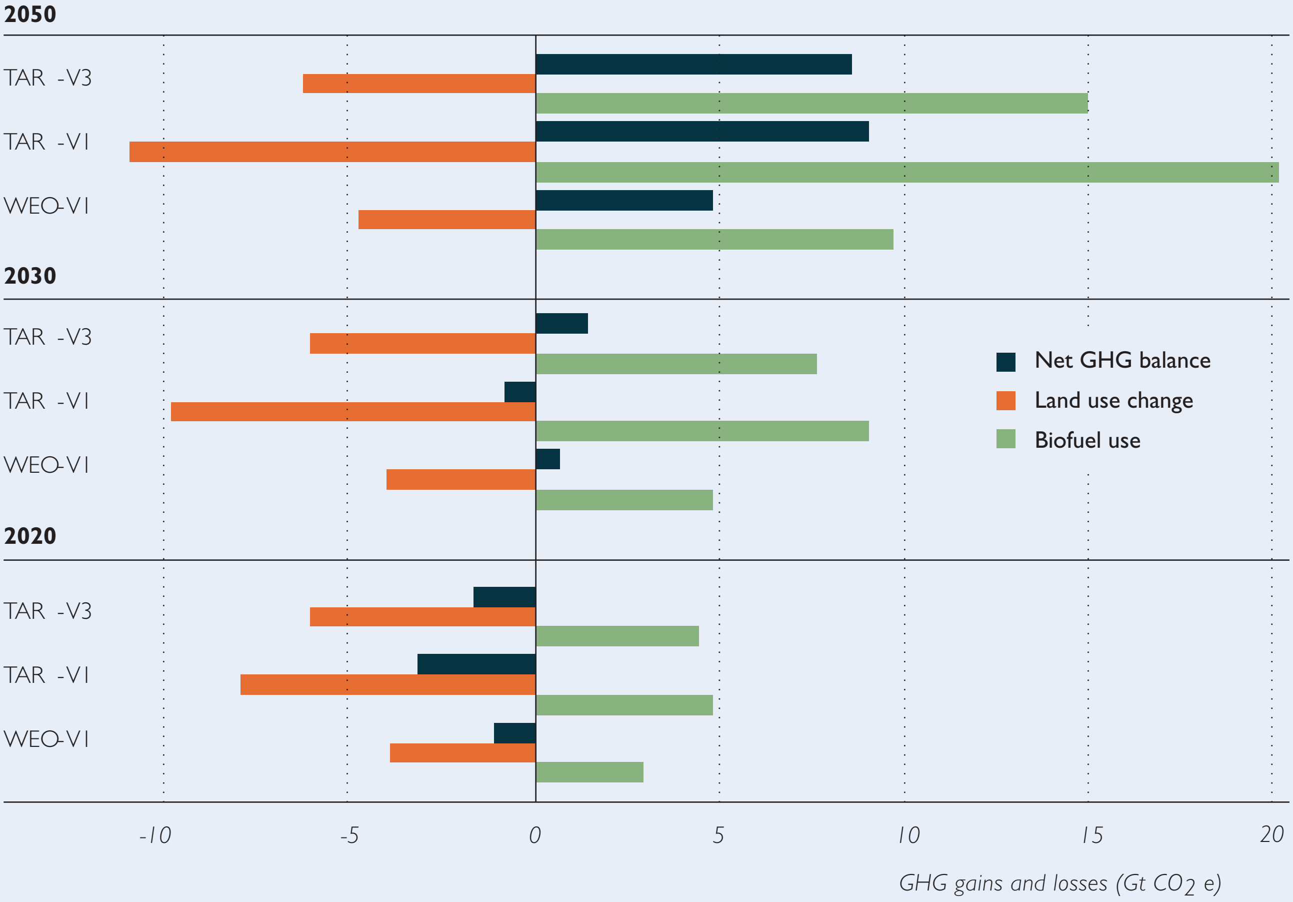
Carbon losses from vegetation and soils due to land use change occur at the time of land conversion, but greenhouse gas savings resulting from use of biofuels rather than fossil fuels accumulate only gradually over time. We therefore calculated and compared the net balance of accumulated greenhouse gas savings due to fossil fuel substitution and the cumulated carbon losses resulting from land use changes (direct and indirect) for several

Cumulative greenhouse gas gains and losses of first-generation biofuels Table 3.5 - 1

Scenario	Accumulated GHG savings from first-generation biofuels for period			Cumulative carbon losses due to additional direct and indirect land use changes		
Gt CO_2e	*2000-2020*	*2000-2030*	*2000-2050*	*2000-2020*	*2000-2030*	*2000-2050*
WEO-V1	1.6 - 2.4	3.3 - 4.8	7.6 - 11.0	4.0	4.1	4.9
WEO-V2	1.6 - 2.4	3.4 - 5.0	8.5 - 12.4	4.2	4.7	7.1
TAR-V1	2.7 - 4.0	6.4 - 9.3	16.3 - 23.4	8.0	9.9	11.0
TAR-V3	2.5 - 3.7	5.4 - 7.8	12.1 - 17.2	6.1	6.2	6.4

Note: The range shown results from using low and high estimates of greenhouse gas savings for biofuels produced from different feedstocks.

Net cumulated greenhouse gas savings of first-generation biofuels Figure 3.5 - 6



Note: Based on GHG saving coefficients in Commission of the European Communities (2008) and IPCC Tier 1 approach for carbon losses due to land use changes (IPCC, 2006).

periods, namely for 2000-2020, 2000-2030 and 2000-2050. Results of different biofuel scenarios are summarized in Table 3.5-1 and Table 3.5-2.

Table 3.5-1 compares the estimated greenhouse gas savings obtained by substituting fossil transport fuels with the biofuels produced in the respective scenario (savings are shown in the left part of the table) with the carbon losses caused by simulated additional direct and indirect land use changes in each biofuel scenario. Both indicators compare outcomes of a biofuel scenario to a reference simulation without biofuels. Results are in carbon dioxide equivalent (CO_2e). For energy savings from biofuels this is done by applying a value of 86 g CO_2e per MJ of fossil fuel saved; for carbon the conversion from C to CO_2 is done by applying molecular weight, i.e. a conversion factor of 44/12 = 3.667 (IPCC, 2006). The ranges shown for greenhouse gas savings were obtained by using for each feedstock commodity respective ranges of greenhouse gas savings given in the literature (e.g., IEA, 2006; FAO,

Net cumulated greenhouse gas savings of first-generation biofuels Table 3.5 - 2

Scenario	Net greenhouse gas savings of first-generation biofuels		
Gt CO_2e	*2000-2020*	*2000-2030*	*2000-2050*
WEO-V1	-2.4 to -1.6	-0.8 to 0.7	2.8 to 6.2
WEO-V2	-2.6 to -1.8	-1.3 to -0.3	1.4 to 5.3
TAR-V1	-5.3 to -4.1	-3.5 to -0.6	5.3 to 12.4
TAR-V3	-3.6 to -2.5	-0.8 to 1.6	5.7 to 10.8

Note: The ranges shown result from using low and high estimates of greenhouse gas savings for biofuels produced from different feedstocks.

2008a; Fritsche & Wiegmann, 2008; Commission of the European Communities, 2008).

The net balance of greenhouse gas savings and carbon losses associated with different biofuel scenarios assessed in this study and accumulated for different time periods is shown in Table 3.5-2. Scenario results of calculations based on greenhouse gas emission coefficients proposed in a recent draft for an EU Directive on the promotion of the use of energy from renewable sources (Commission of the European Communities, 2008) are shown in Figure 3.5-6.

The results clearly show that estimated net greenhouse gas savings resulting from expansion of first-generation biofuels could only be expected to materialize after 30 to 50 years. For shorter periods, to 2020 and up to 2030, net greenhouse gas balances are dominated by carbon debts due to direct and indirect land use changes. Even for the period 2000–2050, maximum cumulated gains of 12.4 Gt carbon dioxide equivalent (scenario TAR-V1) need to be put in perspective to current annual greenhouse gas emissions of 6.4 Gt CO_2e caused by the transport sector.

This result on greenhouse gas impacts and the study outcomes described earlier regarding agricultural prices and food consumption, both indicate that any expanded use of first-generation biofuels would need to be preceded by concerted research and extension efforts to increase overall agricultural productivity in all regions. The foremost priority is to ensure that future food demand is met at affordable prices and only then can any surplus crop production be used for biofuels production. Only with such careful and coordinated planning the negative impacts on food security and greenhouse gas emissions could possibly be avoided. Alternatively, a more likely and prospective development direction is to avoid food security conflicts by producing biofuel feedstocks on land not required or suitable for food production, and by choosing feedstock production and conversion routes that are much superior to first generation pathways. This points to the need for rapid development of second-generation technologies.

3.6 Second-generation biofuels

The previous sections have demonstrated that the concerns about expanding the use of first-generation biofuels, especially when derived from cereals and oilseeds, are well justified in view of their possible impacts on agricultural prices, food security, and their modest contribution to greenhouse gas savings.

In this situation, second-generation biofuels, produced from woody or herbaceous non-food plant materials as feedstocks, have attracted great attention in the hope that substantial technological and economic barriers, which still hamper a commercial deployment of second-generation technologies, can be resolved in the near future and that they will soon become fully commercialized.

Some of the problems associated with first-generation biofuels can be avoided by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks. First, the energy yields per hectare achievable with second-generation feedstocks are generally higher than those of first-generation biofuels, and secondly different quality land could possibly be used for production, thus limiting or avoiding land use competition with food production as lignocellulosic feedstocks are expected to be mainly grown outside cultivated land.

Following substantial government grants recently made to develop second-generation feedstocks and conversion technologies, and based on the announced plans of companies developing second-generation biofuel facilities, an optimistic view is that first fully commercial-scale operations could possibly be

Share and total amount of second-generation biofuels, by scenario Table 3.6-1

Scenario	Share of second-generation fuels in total transport biofuels (percent)			Use of second-generation biofuels (Mtoe)		
Global average	*2020*	*2030*	*2050*	*2020*	*2030*	*2050*
WEO-V1	3	13	30	3	17	62
WEO-V2	0	0	10	0	0	21
WEO-V3	13	30	49	13	38	103
TAR-V1	2	12	26	5	37	110
TAR-V2	0	0	10	0	0	42
TAR-V3	22	38	55	41	113	234
Developed countries						
WEO-V1	4	19	40	3	15	50
WEO-V2	0	0	10	0	0	12
WEO-V3	18	36	59	11	29	73
TAR-V1	4	18	39	5	32	84
TAR-V2	0	0	10	0	0	21
TAR-V3	33	51	68	39	91	146

Indicative biofuel yields of second-generation conversion technologies Table 3.6 - 2

	Biofuel yield liters/dry ton		Energy content MJ/liter	Energy yield GJ/dry ton		Biomass input dry ton/toe	
Process	*Low*	*High*	*LHV*	*Low*	*High*	*Low*	*High*
Biochemical							
Enzymatic hydrolysis ethanol	110	300	21.1	2.3	6.3	18.0	6.6
Thermo-chemical							
FT-Diesel	75	200	34.4	2.6	6.9	16.2	6.1
Syngas-to-ethanol	120	160	21.1	2.5	3.4	16.5	12.4

Source: IEA (2008b)

seen as early as 2012. However, with the complexity of the technical and economic challenges involved, a more realistic expectation is that wide deployment of commercial plants is unlikely to begin before 2015 or 2020. Therefore it is still uncertain what contribution second-generation biofuels will make by 2030 to meeting the global transport fuel demand (IEA, 2008b).

These uncertainties have been included in the scenario analysis of this study by simulating the outcomes for a range of assumptions on the expected share of biofuels that will be contributed by second-generation fuels (see Table 3.6-1).

Three variants were evaluated for each major energy scenario. The share of second-generation biofuels in total biofuels is assumed in the WEO-based scenario in 2020 to range on average from 0 to 33 percent for developed economies, and from 0 to 13 percent for the global average. For the target scenario (TAR) variants this share in 2020 ranges from 0 to 33 percent for developed countries (due to ambitious US targets), and 0 to 22 percent globally. In 2030, the assumed second-generation shares in the WEO and TAR scenarios reach respectively 36 and 51 percent in developed countries, and respectively 30 and 38 percent globally. In absolute terms, the highest use of second-generation biofuels amounts to 41 Mtoe in 2020 and to 113 Mtoe in 2030 of which respectively 39 Mtoe and 91 Mtoe would be accounted for by use in developed countries.

A recent report published by the IEA states that both principal conversion processes, the biogeochemical conversion of cellulose to ethanol and the thermo-chemical conversion to FT-diesel, can potentially convert 1 dry ton of biomass (with about 20GJ/ton energy content) to around 6.5 GJ of energy carrier in the form of biofuels, i.e. an overall biomass to biofuel conversion efficiency of nearly 35 percent (IEA, 2008b). Ranges of indicative biofuel yields per dry ton of biomass are shown in Table 3.6-2.

Assuming that on average biochemical ethanol yields of 250 liters per dry ton biomass will be achievable in 2020 and 300 liters per dry ton in 2030, and respectively 160 liters per dry ton and 200 liters per dry tons will result from thermo-chemical Fischer-Tropsch diesel conversion, then for each ton oil equivalent of second-generation biofuels an average 7.7 dry tons biomass are needed in 2020 and 6.4 dry tons by 2030. A value of 6 dry tons per toe is assumed for 2050. This results in a biomass demand for second-generation biofuels as listed in Table 3.6-3.

Rapid deployment of second-generation conversion technologies after 2015 in order to meet the biofuel production of the target

(TAR-V3) scenario in 2020 and 2030 would require some 315 million dry tons of biomass in 2020, increasing to 725 million dry tons in 2030. Of this about 300 million dry tons in 2020 and nearly 600 million dry tons would be required to meet demand in developed countries.

Impact of second-generation biofuels on greenhouse gas savings

The previous section highlighted the modest contribution of first-generation feedstocks to greenhouse gas savings. Here we provide a similar account for second-generation biofuels across different scenarios. A summary is shown in Table 3.6-4.

Biomass demand for second-generation biofuels, by scenario Table 3.6 - 3

Scenario	Global biomass demand for second-generation biofuels (million dry tons)			Biomass demand for second-generation biofuels in developed countries (million dry tons)		
	2020	*2030*	*2050*	*2020*	*2030*	*2050*
WEO-V1	19	106	370	19	95	300
WEO-V2	0	0	125	0	0	74
WEO-V3	97	240	615	87	186	440
TAR-V1	35	234	660	35	207	500
TAR-V2	0	0	254	0	0	128
TAR-V3	315	725	1402	297	583	875

Net cumulated greenhouse gas savings of second-generation biofuels Table 3.6 - 4

Scenario	Net greenhouse gas savings of second-generation biofuels		
Gt CO_2e	*2000-2020*	*2000-2030*	*2000-2050*
WEO-V1	< 0.05	0.1 to 0.4	1.8 to 3.3
WEO-V2	0	0	0.4 to 0.8
TAR-V1	< 0.05	0.2 to 0.8	3.4 to 6.2
TAR-V3	-0.2 to 0.6	1.4 to 3.5	9.4 to 16.2

Note: The ranges shown result from using low and high estimates of greenhouse gas savings as discussed below.

Net cumulated greenhouse gas savings of biofuels scenarios Table 3.6 - 5

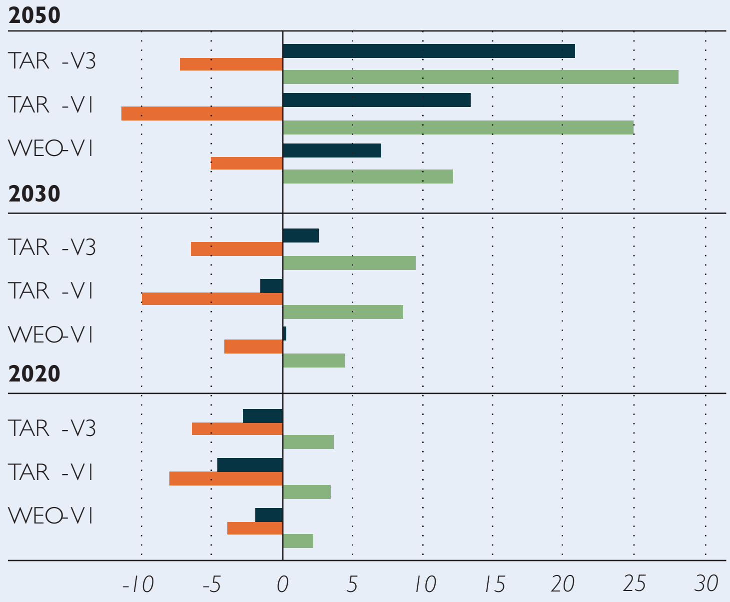
Scenario	Net greenhouse gas savings of first- and second-generation biofuels		
Gt CO_2e	*2000-2020*	*2000-2030*	*2000-2050*
WEO-V1	-2.4 to -1.6	-0.7 to 1.1	4.5 to 9.4
WEO-V2	-2.6 to -1.8	-1.3 to 0.3	1.8 to 6.1
TAR-V1	-5.3 to -4.0	-3.2 to 0.2	8.7 to 18.6
TAR-V3	-3.8 to -1.8	0.7 to 5.0	15.1 to 27.0

Note: The ranges shown result from using low and high estimates of greenhouse gas savings for different feedstocks as discussed in the text.

For the low estimate shown in Table 3.6-4 we assume, consistent with the available literature, that at least 70 percent greenhouse gas saving can be achieved with second-generation biofuels. For the high estimate we adopt values from the literature suggesting that with advanced technologies and combined generation of biofuels and heat or electricity 100 percent (or even more) greenhouse gas savings are possible. As to carbon impacts of land use changes, we assume that second-generation feedstocks will be grown on 'non-food' land, primarily grassland and woodland, under no-till management. This land use strategy would result in only small losses of soil carbon. The pessimistic assumption is that up to 10 percent of soil carbon may be lost in grassland and woodland (low estimate). As second-generation feedstocks may develop more vigorous rooting systems and above-ground vegetation than existed before land conversion, the high estimate assumes a balanced situation, i.e. no losses or gains of carbon due to land conversion.

Rapid deployment of second-generation biofuels can bring about much higher greenhouse gas savings than is possible with first-generation biofuels as shown, for instance, when comparing variant TAR-V1 (26 percent second-generation biofuels in 2050) to scenario variant TAR-V3 (55 percent second-generation biofuels in 2050) in Table 3.6-5 and Figure 3.5-7. While the total amount of biofuels used is the same in both variants, net greenhouse gas savings are higher in TAR-V3 by 6.4 Gt to 8.6 Gt carbon dioxide equivalent compared to TAR-V1.

Net cumulated greenhouse gas savings of biofuel scenarios Figure 3.5 - 7



Note: Computations for first-generation biofuels are based on greenhouse gas saving coefficients in Commission of the European Communities (2008) and IPCC Tier 1 approach for carbon losses due to land use changes (IPCC, 2006). For second-generation biofuels a greenhouse gas saving of 85 percent was used.

Typical yields of second-generation biofuel feedstocks* Table 3.6 - 6

dry tons/hectare	Current yields	Expected yield by 2030
Miscanthus	10	20
Switchgrass	12	16
Short rotation willow	10	15
Short rotation poplar	9	13

Source: Worldwatch Institute (2007)

*These yields refer to generally good land; under marginal conditions, yields can be substantially lower

Land required for second-generation biofuels

Low-cost crop and forest residues, wood process wastes, and the organic fraction of municipal solid wastes can all be used as lignocellulosic feedstocks. In some regions substantial volumes of these materials are available and may be used. In such cases, the production of biofuels requires well-designed logistical systems but no additional land is needed. In other regions, with limited residues and suitable wastes and where large and growing amounts of feedstocks are demanded, additional land will be needed for establishing plantations of perennial energy grasses or short rotation forest crops. Typical yields for the most important suitable feedstocks are summarized in Table 3.6-6.

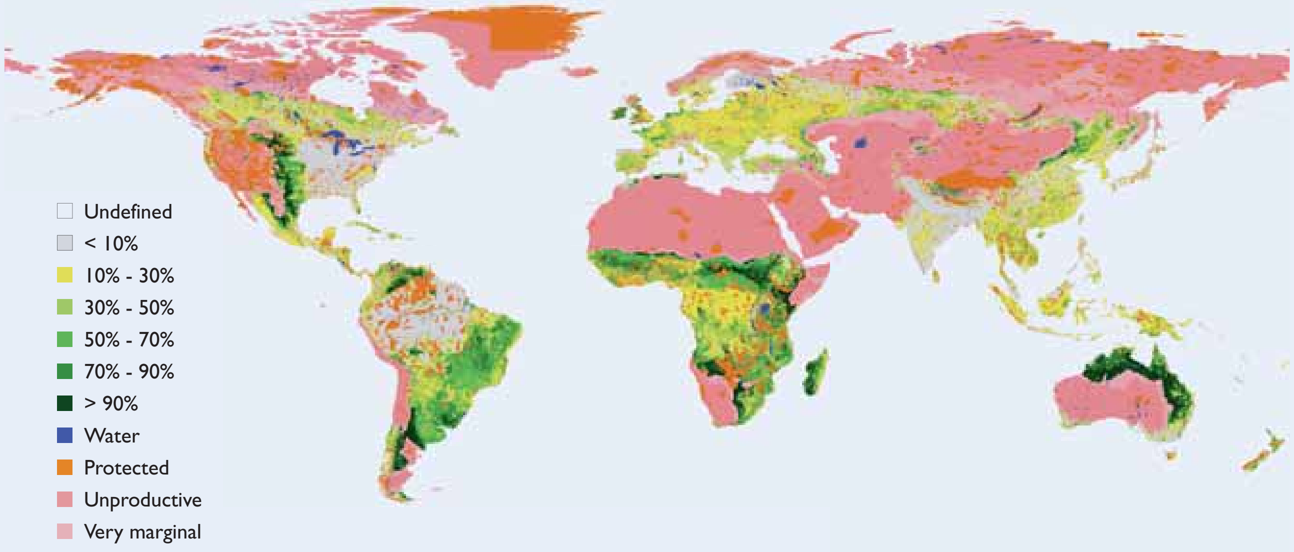
Taking an average typical yield of around 10 dry tons per hectare as possible and reasonable in 2020, then the biomass requirements listed in Table 3.6-3, a maximum of 315 million dry tons in 2020, implies that up to 32 million hectares of land would be needed if all biomass were to come from plantations. In reality the land requirement in 2020 will be much lower due to large amounts of cheap crop and forest residues available. In this early stage of second-generation biofuel development most of the biomass would be required in developed countries. By 2030, assuming that research as well as learning would increase average yields to about 15 dry tons per hectare (as suggested in Table 3.6-6), then an upper limit of land required for feedstock production would be 50 million hectares in the TAR-V3 scenario and less than 20 million hectares in both WEO-V3 and TAR-V1 scenarios.

While conventional agricultural feedstocks currently used in first-generation biofuel production compete with food crops, second-generation lignocelluloses technologies promise substantial greenhouse gas savings and may permit tapping into land resources currently not or only extensively used. Acknowledging these significant advantages of second-generation lignocellulosic biofuel feedstocks over conventional agricultural feedstocks, we employed a detailed geographical resource database (Fischer et al., 2008) to estimate land potentially available for bioenergy production under a "food and environment first" paradigm, i.e., excluding land currently used for food and feed production as well as excluding forests.

In this estimation, based on a 5' by 5' latitude/longitude grid (i.e. about 10 km by 10 km at the equator), we started from total land area and subtracted all land indicated as artificial and built up surfaces, all cultivated land and current forest land. In a next step all areas indicated or designated as legally protected

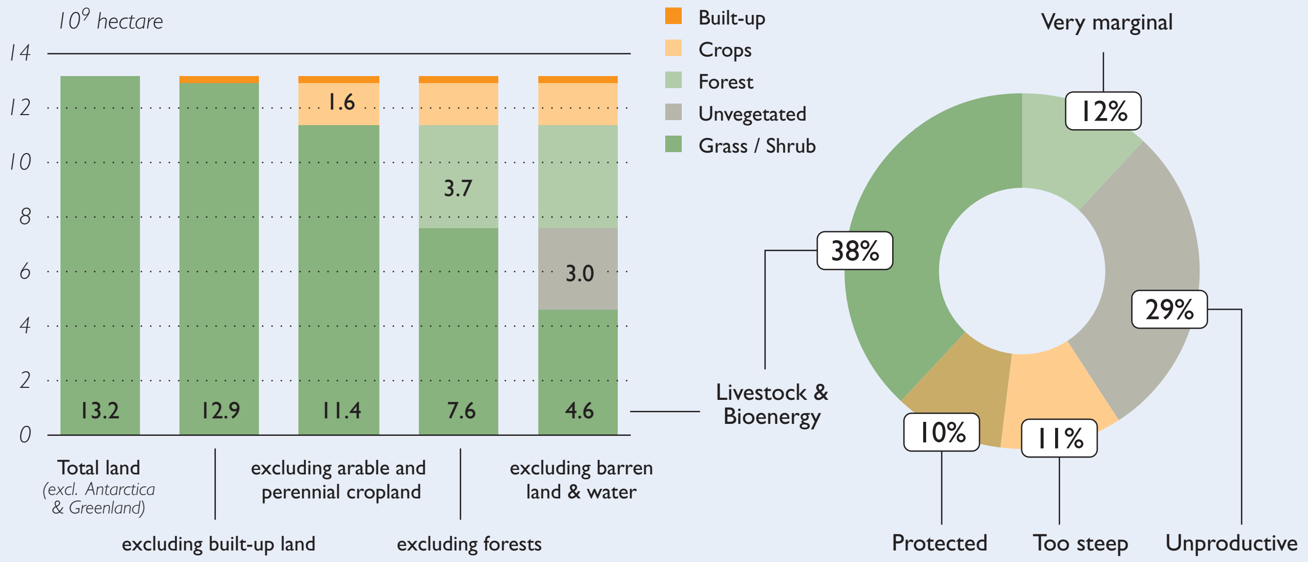
Spatial distribution and share of land by 5' latitude/longitude grid cell currently classified as unprotected grassland and woodland potentially useable for rain-fed lignocellulosic biofuels feedstock production

Figure 3.6 - 1



Source: Fischer et al. (2008).

Balance of land classified as unprotected grassland and woodland potentially useable for rain-fed lignocellulosic biofuel feedstock production Figure 3.6 - 2



Source: Fischer et al. (2008).

were excluded. Then land was excluded with very low productivity, either due to cold temperatures in the high latitudes or high altitudes, or because of low annual precipitation, as well as land unsuitable because of steep sloping conditions. Spatial results of the distribution of remaining potentially available areas are shown in Figure 3.6-1. The very low or unproductive land (shown in red colors) covers large areas in northern Eurasia and northern Canada, the Australian and central Asian arid and semi-arid lands, the horn of Africa and sparse grasslands in the western parts of southern Africa. Higher intensities of potentially useable grass and wood land are shown in the US Great Plains, sub-humid sub-Saharan Africa and large stretches in South America.

A global account of the balance of the land currently classified as grassland and woodland potentially useable for lignocellulosic biofuel feedstock production is shown in Figure 3.6-2. Excluding from a total global land area of 13.2 billion hectares (excl. Antarctica and Greenland) all current cultivated land, forests, built-up land, water and non-vegetated land (desert, rocks, etc.) resulted in 4.6 billion hectares remaining land area (35 percent of total; see Figure 3.6-2). Excluding from these extents the unproductive, very low productive (e.g. tundra, arid land) or steeply sloped land, a remaining area of 1.75 billion hectares (see Table 3.6-7) was estimated, which comprises of grassland and woodland. Over two-thirds of this grassland and woodland potentially suitable for biofuels feedstock production is located in developing countries, foremost in Africa and South America (Table 3.6-7). These estimates are to be understood as indicative only and are subject to the limitations and accuracy of global land cover, soil and terrain data.

An important current use of these land resources is livestock grazing. Using available UN FAOSTAT data on feed utilization of crops and

Regional balance of land classified as unprotected grassland and woodland potentially useable for rain-fed lignocellulosic biofuel feedstock production

Table 3.6 - 7

REGION	TOTAL GRASS- AND WOODLAND	OF WHICH			POTENTIAL RAIN-FED YIELD		
		Protected areas	Unproductive or very low productive	Balance of grass- and woodland	Average	Low	High
	mill. ha	*mill. ha*	*mill. ha*	*mill. ha*	*dry t/ha*	*dry t/ha*	*dry t/ha*
North America	659	103	391	165	9.3	6.7	21.4
Europe & Russia	902	76	618	208	7.7	6.9	14.5
Pacific OECD	515	7	332	175	9.8	6.5	20.0
Africa	1086	146	386	554	13.9	6.7	21.1
Asia, East	379	66	254	60	8.9	6.4	19.0
Asia, South	177	26	81	71	16.7	7.6	21.5
Latin America	765	54	211	500	15.6	7.1	21.8
Middle East & N.Africa	107	2	93	12	6.9	6.3	10.6
Developed	2076	186	1342	548	8.9	6.7	21.0
Developing	2530	295	1029	1206	14.5	6.8	21.5
World	4605	481	2371	1754	12.5	6.8	21.5

Source: GAEZ (2008)

processed crop products (e.g. oilseed cakes and meals), production of fodder crops, national livestock numbers and livestock production, we estimated the feed energy provided by these recorded sources in each country in order to determine the energy gap to be filled by grassland and pastures. The results of detailed livestock feed energy balances suggest that in year 2000 about 55-60 percent of the available grassland biomass globally was required for animal feeding. This share is about 40 percent in developed countries. It amounts to an average 65 percent for developing countries, with values for Asian regions larger than 80 percent and about 50 percent in sub-Saharan Africa (see Box 3.6-1).

Hence, at current use levels, the land potentially available for bioenergy production (assuming unbiased distribution between livestock feeding and bio-energy uses) was estimated in the order of 700 – 800 million hectares, characterized by a rather wide range of productivity levels. Of these extents an estimated 330 million hectares are in the developed countries (about one-third each in North America, Europe & Russia & Central Asian republics, and Pacific OECD). About 450 million hectares of this land were estimated for the developing countries; 275 million hectares in Africa and 160 million hectares in Latin America. Some regional details of the estimated land areas and potential yields of second-generation lignocellulosic feedstocks are presented in Table 3.6-7.

We have subtracted only the demand for livestock feeding as the main current alternative use. No allowances were included for other social or environmental functions of the land, e.g. as feed source for wildlife. Also, estimates are subject to uncertainties regarding grass and

Is there enough land for food and energy in Sub-Saharan Africa?

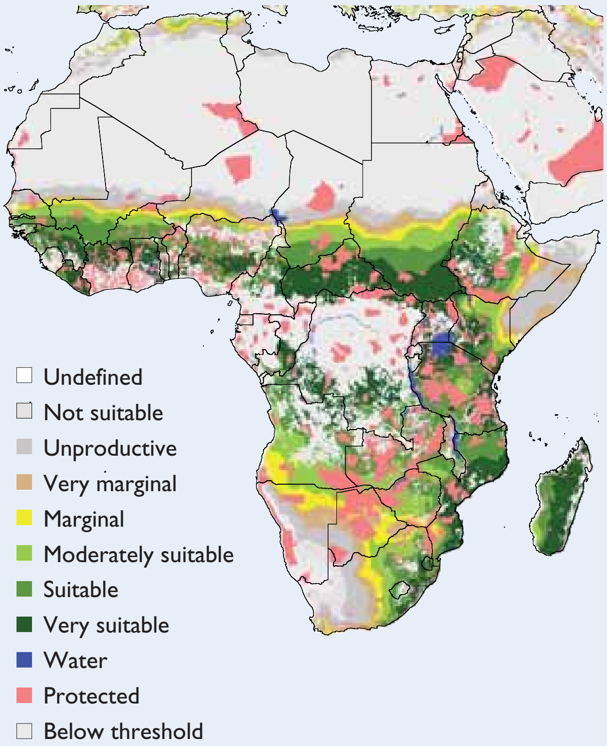
Box 3.6 - 1

In Africa, less than 9 percent of the total land area of 3 billion hectare is currently used for crop production, 45 percent of the land being water bodies, desert, barren, steeply sloped, or very marginally productive, 18 percent being forest and 6 percent otherwise protected land, and less than 1 percent urban and built-up areas. Pastures, savanna and bush cover 22 percent of the land, with a wide range of bio-productivity. We estimate that about half of the annual biomass produced in these areas is currently needed to support ruminant livestock (see figure 3.6-3). Though the key to enhancing food security will be achieving sustainable yield increases on current cultivated land, up to a third of this savanna and bush, i.e. 175-200 million hectares, could be used for food and energy production.

While conventional agricultural feedstocks currently used in first-generation biofuel production compete with food crops and perform poorly for environmental criteria, second-generation technologies promise substantial greenhouse gas savings and may permit tapping into land resources currently not or only marginally used.

Figure 3.6 - 3a:

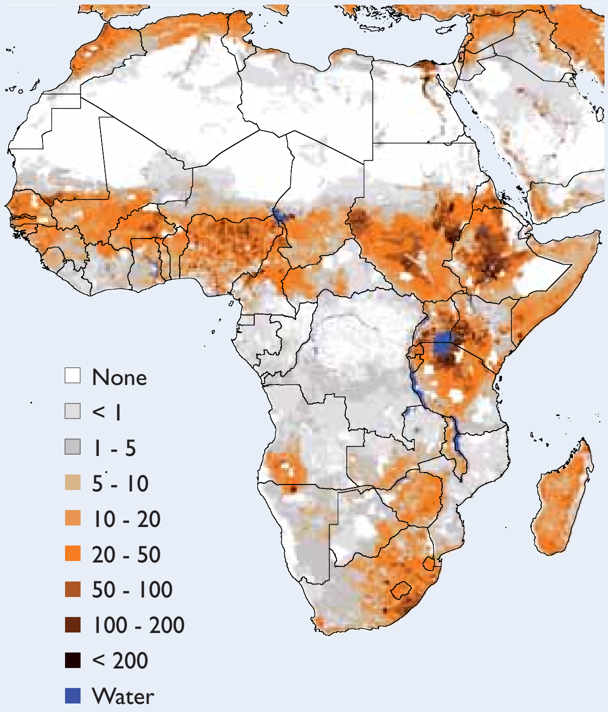
Bio-productivity of grassland and woodland



Source: Fischer et al. (2008)

Figure 3.6 - 3b:

Density of ruminant livestock



Source: www.fao.org

Typical scale of operation for second-generation biofuel plants Table 3.6 - 8

Type of plant	Plant capacity *1000 liters/year*	Biomass demand *dry tons/year*	Truck vehicle movements for biomass delivery	Land area required for biomass production
Small pilot	15 – 25	40 – 60	3 – 5 / year	1 – 3% within 1 km
Demonstration	40 – 500	100 – 200	10 – 140 / year	5 – 10% within 2 km
Pre-commercial	1,000 – 4,000	2,000 – 10,000	25 – 100 / month	1 – 3% within 10 km
Commercial	25,000 – 50,000	60,000 – 120,000	10 – 20 / day	5 – 10% within 20 km
Large commercial	150,000 – 250,000	350,000 – 600,000	100 – 200 / day	1 – 2% within 100 km

Source: IEA (2008b)

pasture yields, which due to scarcity of measured data had to be estimated in model simulations with the IIASA/FAO GAEZ model (Fischer et al., 2008).

It can be concluded that land demand for producing second-generation feedstocks as required for the most demanding TAR-V3 scenario in 2020 (about 30 million hectares) and in 2030 (about 50 million hectares) could be met without having to compete for cultivated land. The results of the biofuels target scenario with accelerated second-generation biofuels deployment indicate that production of lignocellulosic feedstocks on some 100 million hectares would be sufficient to achieve the biofuels target share in world transport fuels in 2050.

However, there is a need to carefully assess and respect the current uses and functions of potentially suitable land, to regulate land use in an integrated approach across sectors to achieve land use efficiency, avoid conflicts and to protect the rights of the weakest members of society when land ownership is uncertain. Another major challenge is development of the massive infrastructure and logistical systems required for second-generation feedstock supply systems.

The enormous logistical tasks connected with second-generation biofuel plants are indicated in Table 3.6-8. As reported by IEA (2008b), it lists the typical scale of operation for various second-generation biofuel plants running on the basis of lignocellulosic feedstocks. For commercial and large commercial plants the annual feedstock required is respectively up to 120,000 and 600,000 dry tons of biomass, i.e. an average daily supply of about 330 to 1650 dry tons. As feedstocks for economic operation of a large biomass-based plant typically have to be produced within a radius of 50 to 100 km, there are also clear implications for land use intensity of energy plantations. At an average yield of 10 dry tons per hectare, if the biomass were to be produced within 50 km around a large commercial plant, then at least 8 percent of the land surface would need to be allocated to plantation crops; for a radius of 100 km this would reduce to 2 percent of the area.

Part IV: **Conclusions and Policy Implications**

Conclusions and Policy Implications

Food security, rural development, energy security and climate change mitigation are all critical to social, economic and environmental sustainability at national to global levels. A successful resolution of these challenging issues requires the goodwill and commitment of all nations to work together. Biofuel polices have a direct impact on these quadruple challenges and yet it is national polices, including mandates and targets setting, with national interests that have been the driving force of biofuels developments.

The results of this study include a detailed review of the status of biofuels developments around the world and of the public policy regimes and support measures driving this evolution. An integrated ecological-economic modeling approach was used to comprehensively evaluate the social, environmental and economic impacts and implications of biofuels targets on food security, transport fuel security, climate change mitigation, rural development, land use change and biodiversity risks and sustainable agricultural development partnerships. The quantified results of the aggregate implications of the current biofuels targets set by various countries, presented in this report, are relevant to policy-making with regard to the choice of the "specific and best" biofuels feedstocks.

IIASA's global and spatial agro-ecological and socio-economic assessment framework provides the analytical means and science-based knowledge to assess policy options for making informed choices that avoid pitfalls and mobilize the opportunities of biofuels. Main conclusions and policy implications derived from the global quantitative analysis are summarized below.

First-generation biofuels global expansion will threaten food security in developing countries

- As population growth is continuing and per capita incomes are increasing, land demand for food and feed will continue to grow as well. Any substantial contributions of agriculture to producing transport fuels, without stressing the world food system, will therefore necessitate achievement of sustainable production increases on current agricultural land – well beyond projected business-as-usual scenarios – and tapping into land resources which are currently not or extensively used for agriculture with scope for more intensive utilization. Yield increases, careful use of agricultural inputs and effective land use regulation will be essential to alleviating land use pressure, safeguarding food security, avoiding environmental damages and minimizing biodiversity losses.
- Achieving biofuels targets in 2020 will require an additional cereal use for ethanol production of some 150 to 240 million tons (depending on the speed of second-generation biofuel development), i.e. some 5-9 percent of total cereal use. In 2030 this estimated additional cereal use amounts to 190 to 350 million tons (6-11 percent of total ce-

real use). We estimate that additional cereal production will account for two-thirds to three-quarters of the cereal feedstocks used for ethanol production. At the same time cereal food and feed use will decline compared to the reference scenario (without additional biofuels) equivalent to 10 percent and 25 percent respectively of the cereals used for biofuels production. Developing countries make up 75 percent of this 'forced' reduction in cereal food consumption. The results highlight the need to protect developing countries against market impacts caused by first-generation biofuel development. An important element here will be achieving an early transition to second-generation biofuels to reduce food-fuel competition and lessen food security impacts.

- First-generation biofuels expansion will have considerable impacts on world food prices as a consequence of food – feed – fuel use competition. For example in 2020, a production level of first-generation biofuels contributing a 2, 4 or 6 percent share in total transport fuels results in world cereal price increases of the order of 5, 20 and 34 percent respectively. Such increases will cause a serious deterioration of food security in many developing countries with limited domestic food production and lack of foreign exchange earnings to finance essential food imports.
- Achieving current biofuels targets in 2020 with first-generation technologies will increase the number of people at risk of hunger by an additional 140 million. This means an increase of an additional 15 percent on top of 854 million undernourished people projected for 2020 in the reference scenario without biofuels. The Millennium Development Goals have set a target of reducing world hunger by 50 percent over the period 1990 to 2015. First-generation biofuels will exacerbate the tasks of reducing world hunger and it is the poorest of the world population that will bear the brunt of the consequences.
- In the long run current first-generation biofuel production on cultivated land is not tenable as the world's limited agricultural land resources are essential to meet future food demand. Hence it is important to make an early transition to zero cultivated land demanding second-generation feedstocks and production chains.

There is a high priority for policies to ensure that biofuel strategies are couched by monitoring and appropriate support measures to protect the poor and food-insecure against impacts of food-fuel competition. The speed and the feedstock choice of biofuels deployment needs to be guided by social criteria, technological advances and actual realized agricultural production gains to prevent imbalances and price surges in rather inelastic and distorted agricultural markets.

Biofuels cannot deliver transport fuel security

- The current biofuels targets would enable a biofuels share in transport fuels of about 8 percent in the developed countries and a 6 percent share in the developing countries in 2020. By 2030, a 12 percent share in the developed countries and some 8 percent in the developing countries would be contributed by biofuels.

The contribution of liquid biofuels based on agricultural crops and plant biomass can only make a limited contribution to global transport fuel use in the next two decades. Biofuels may be a useful element in a portfolio of measures to reduce dependence on fossil fuels. However the major contribution to saving fossil fuels can only be achieved by improving fuel efficiency in all transport sectors. Therefore policy-makers need to recognize that biofuels can provide only partial and insufficient answers to energy independence and decarbonization of the transport sector.

Climate change mitigation is crucial and biofuels are an insufficient answer

- Current biofuels targets could result in additional loss of forests of about 15 million hectares during 2000-2020. Deforestation causes substantial emissions of carbon stocks in soils and vegetation, and this defeats one of the primary goals of biofuels to contribute to climate change mitigation.
- Net greenhouse gas savings from first-generation biofuels development will only materialize after about 30 years for reasons of relatively higher carbon emissions from direct and indirect land use changes during the initial 30-year period. Even estimates for the period 2000–2050, cumulative net gains of 15-27 Gt carbon dioxide equivalent due to biofuels use, need to be put in perspective to current annual greenhouse gas emissions of 6.4 Gt carbon dioxide equivalent caused by the transport sector. The reality and risks of climate change require a multi-pronged effort to reduce greenhouse gas emissions. First-generation biofuels development is an insufficient and mostly ineffective means to meet the challenges of climate change mitigation.
- A noteworthy exception to the above conclusions regarding first-generation biofuels is sugar-cane based ethanol as produced under 'best practice' in Brazil with the following characteristics: mainly rain-fed cultivation; a high degree of nutrient recycling from by-products and residues to sugar cane fields; intensive research to increase yields and achieve high land use efficiency; land conversion for production expansion mainly from former pastures and grassland; high ratio of energy output to fossil energy input; greenhouse gas savings of 80 percent and more; production costs competitive with fossil fuels. Thus Brazilian sugar-cane based ethanol production entails several desirable characteristics claimed for second-generation biofuels.

Research in recent years has demonstrated that the wide diversity of options for producing biofuels results in a broad and uncertain range of greenhouse gas impacts, primarily due to large differences in land productivity, land management practices and foremost land conversion. As there are real risks that short term objectives and incentives could promote biofuel systems that are counter-productive as regards greenhouse gas emissions, policies must ensure that biofuel use contributes to climate mitigation. It is widely acknowledged that land use regulation is critical to biofuels development, both for sake of carbon stock protection as well as for reducing land use competition.

Biofuels may enhance rural development, but only modestly

- The contribution of biofuels development to increasing agriculture value added is limited, some 6-8 percent in the developed countries and only about 3 percent in the developing countries by 2030. Often claimed benefits of biofuels to foster rural development cannot rely on feedstock production alone; it will also require the setting up of the entire biofuels production chain.
- The substantial potential for large scale commercial production of second-generation biofuels feedstocks in tropical grasslands and woodlands offers scope and opportunity to develop innovative and mutually beneficial private sector and local community partnerships that would produce not only biofuels but also food for and by the local community. Rural local communities in many developing countries are often food insecure and poor with few options for employment and incomes. Partnerships will need to be well designed and legally binding to minimize social and economic risks of exploitation as well as environmental risks of soil carbon emissions and biodiversity loss. With mutual commitments and equitably shared benefits a sustaining and a secured pro-poor partnership can be built

As on one hand most of the advanced biofuel technologies are likely to come into being in developed countries but on the other hand the larger fraction of suitable land resources is in developing countries, there is a clear need for effective mechanisms to transfer new technologies to and among developing countries. While expansion of biofuels could promote growth in developing countries, it is not clear that income generated would be shared equitably or even stay in the country. A fair distribution of ownership rights is an important element of sustainable social and economic development including guaranteeing the local communities' ownership over their land.

Biofuels expansion will put biodiversity at risk

- Total global cultivated land use increases by 20-30 million hectares in 2020 and by 20-45 million hectares in 2030 (depending on the speed of second-generation biofuels emergence) when meeting the additional biofuels target demands. While this expansion of cultivated land is only 1 to 3 percent of total use across scenario variants with biofuels targets as compared to no additional biofuels, the impact is much more substantial when viewed in terms of land expansion. In this sense, the impact of biofuels scenarios is to increase the baseline (without biofuels) net expansion of cultivated land during 2000-2020 by 20-40 percent, and by 15-30 percent during 2000-2030.
- First-generation biofuels feedstocks, grown in large scale monocultures with intensive fertilizer applications and use of biocides to control weeds and combat pests and diseases, will have a negative effect on biodiversity. Conversion of natural ecosystems, especially natural forests and natural grassland, generally causes considerable losses of biodiversity; impacts of using abandoned or degraded agricultural land or low intensity grazing lands are relatively less. The scale of conversion in combination with large scale mono-cropping without compensating through e.g. "habitat islands" and "migration corridors" may have far reaching negative impacts on biodiversity.

As highlighted in this report, the growing future food demand will require expansion of cultivated land, a trend exacerbated by accelerated biofuels production. Extensive monitoring of land cover conversion, especially deforestation, is essential. Incentive schemes aiming at avoidance of deforestation should be negotiated at the international level, for example in the context of mechanisms in (post-Kyoto) agreements on combating climate change. When agricultural productivity increases are achieved by means of large-scale monocultures with intense fertilizer applications and use of pesticides, this will impact on biodiversity and water quality. This calls for environmental regulation of agricultural production and land use as a whole. Biofuels feedstocks in particular need to be evaluated according to internationally agreed sustainability criteria. These must include preservation of natural forests, highly biodiverse grasslands and wetlands, as well as promotion of best management practices.

Biofuels policies require a global scope and international development partnerships

- Governments of a number of countries such as the United States, Member States of the European Union, Brazil, China, India, Indonesia, South Africa and Thailand have adopted policy measures and set targets for development of biofuels. These policy responses to deal with concerns of transport fuel security and climate change have generally been implemented without a comprehensive assessment of the impacts of biofuels developments at local, national, regional and global levels.

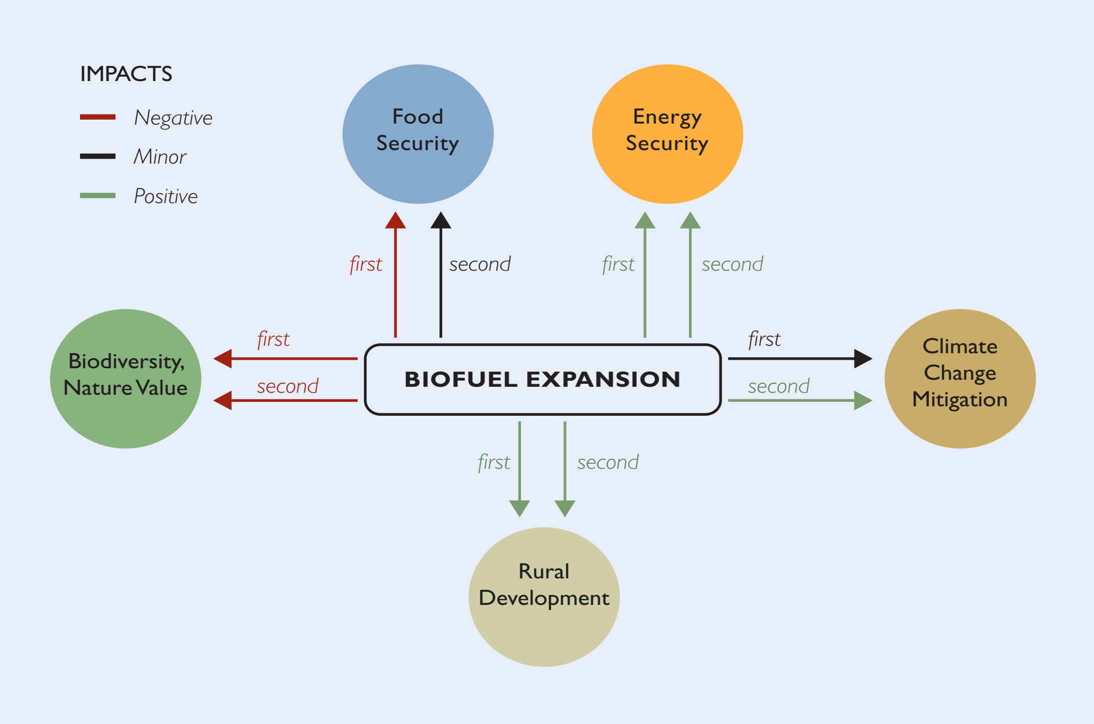
- First-generation biofuels development promoted by national policies is conflicting with goals of achieving food security. It will result in only modest increases of agricultural value added in developing countries, achieve at best only minor net greenhouse gas savings until 2030 and will create additional risks of deforestation and biodiversity loss.
- Second-generation biofuels produced on land other than cultivated land required for food and feed production offer opportunities for the development of environmentally clean and economically competitive biofuels. However this will depend on the timely delivery of efficient and effective second-generation conversion technologies as well as advances in feedstock production and land use regulation.
- There is an urgent need for a spatially detailed interdisciplinary scientific assessment of the risks and opportunities of biofuels, in particular with regard to large uncertainties of second-generation biofuel production and the local availability and current use of grassland and woodland areas.

Biofuel developments cut across several different policy domains and play out at multiple geographical scales from local to global. International cooperation and coordination is indispensable for all aspects of biofuel development: to achieve resource-efficient geographical patterns of biofuel production; to accomplish best possible outcomes with respect to the environmental goals of greenhouse gas emission reduction and nature protection; to bundle research capacities for addressing major technological barriers of second-generation pathways; and to create an international environment promoting investments, technology transfers and adoption of best practices. Specific topics for international coordination include agreed sustainability criteria for biofuel production, monitoring and regulation of land use changes, conservation of biodiversity and protection of terrestrial carbon stocks, mechanisms and accompanying measures to ensure food security, and making biofuels a consistent part of international conventions and policy regimes such as for reducing emissions from deforestation and forest degradation (REDD), the Biodiversity Convention (CBD), the Clean Development Mechanism (CDM), and the rules and standards adopted by the World Trade Organization (WTO).

Biofuels are not all equally 'good' or 'bad' and require knowledge-based policy-making

- Among first-generation biofuel feedstocks the starchy crops for ethanol and oilseeds for biodiesel are least desirable. They achieve no or only little net greenhouse gas savings, are mostly food crops, are grown on cultivated land and require high doses of agro-chemicals.
- Oil palm grows best in environments that in natural state consist of tropical highly biodiverse ecosystems with huge carbon stocks at risk. Oil palm is an environmentally very risky feedstock; when used requires very strict best practice certification.
- There are several appealing aspects of the 'wonder crop' Jatropha (non-food crop, possibility to be grown on non-food land). However, Jatropha is not yet agronomically sufficiently developed. Investment in research and development is still needed prior to large scale introduction. Establishing local community partnerships is risky due to mainly agronomic uncertainty.
- Sugar cane is definitely the best among first-generation biofuel options. Due to a long record of experience and past large research investments, sugar cane ethanol is economically competitive and environmentally efficient. The main risks to be addressed by policy are land conversion (carbon and biodiversity loss) and possibly social exclusions.
- Second-generation feedstock use is promising but is largely unproven. Large invest-

First and second-generation biofuel development implications and policy objectives Figure 4.1-1



ments, high economic risks, required technology improvements and uncertainty as to the availability of non-food land for feedstock production are major hurdles for deployment.

- Recycled oil and fats, crop and forestry residues and wastes are seen as the best-performing feedstocks for biofuel use. While significant in volume and with the possibility to serve as a driving force especially during transition to second-generation biofuels, potential supply of these materials is nevertheless limited.

As a result of intense research efforts in recent years to better understand the energy-food security-environment nexus that characterizes biofuel development, it has become quite obvious that coarse generalizations labeling all biofuels as 'good' or 'bad' are meaningless because their impacts critically depend on the 'what', 'where' and 'how' of an entire biofuel production chain. Clear policy principles are called for to guide biofuel policy support and regulations that avoid economic and environmental pitfalls while responding to the opportunities created by biofuels development.

Figure 4.1-1 sketches the impacts of biofuels expansion with regard to achieving the main policy goals that have motivated biofuels support.

As for agriculture in general, biofuels development is likely to have a negative impact on biodiversity. The importance and magnitude of this effect depends on various local factors: the land use history prior to biofuels production, type of feedstock, use of agro-chemicals, agronomic practices, etc. While positive stimuli to the rural economy and some reduction of fossil energy dependence are likely to be achieved by biofuels development, net greenhouse gas savings of first-generation biofuels (with the exception of sugar cane based ethanol) are close to neutral and may be negative in case of inappropriate land use changes. Second-generation biofuels generally fare better than first-generation fuels, especially with regard to greenhouse gas mitigation and food security impacts. Yet second-generation biofuel production will nevertheless endanger biodiversity.

Agriculture needs to be put as priority on the world's development agenda

Agriculture is the dominant user of environment and natural resources; it has the greatest impact on the sustainability of ecosystems and their services, and accounts directly and indirectly for a major share of employment and livelihoods in rural areas in developing countries. The trends over the last three decades in many developing countries indicate a reduced allocation of national development budgets to agriculture, and this, together with declining multilateral lending and bilateral aid for the agricultural sector exemplifies that agriculture continues to be regarded as "backward" and a low priority. The reality is that no progress on reducing hunger and rural poverty can be achieved without political and resource commitment to sustainable agricultural development. The current interest in enhancing energy security through biofuels development provides for an opportunity to prioritize and put agriculture on national and international development agenda.

Policy challenges and the way forward for biofuels

Liquid biofuels for transport have been strongly acclaimed and heavily criticized in recent months for their potential to benefit society as well as the considerable risks their expansion may pose to food security and environmental sustainability. The analysis undertaken in this study confirms the potential risks of biofuels development when driven by national and domestic short-term policy agendas without coordination and coherence among policies in the involved and impacted sectors including agriculture, transport, energy and environment.

Lessons and conclusions drawn from the quantitative scenario analysis provide guidance towards policies for establishing a socially beneficial and environmentally acceptable way forward with biofuels development and deployment. Coherent policies and policy support measures for sustainable expansion of biofuels require consideration of critical and complementary issues such as:

- **Renewed efforts to enhance agricultural productivity, especially in lacking regions:** Current biofuels systems and the ones likely to be available in the next decade to 2020 rely fundamentally on agricultural crops. Unless sustained and sustainable yield increases can meet additional feedstock demand for biofuels expansion, the obvious consequences would be food price increases on one hand and rapid land conversion to bring more resources into agriculture production on the other hand. In order to create a win-win situation, increasing yields would be most effective in currently lacking regions, notably sub-Saharan Africa. Such development, especially when engaging and focusing on the rural poor, would improve regional food security and could free up land to provide an additional stimulus for biofuels development, thus possibly creating a positive feedback loop for sustainable rural development.
- **Protecting the poor against impacts of rising agricultural prices:** The food crisis in 2007/08 demonstrated that the uncoordinated biofuels development can contribute substantially to short-term price shocks on international commodity markets and may also result in a stable trend of rising food prices. Safety nets are required at the international and domestic levels to shield low-income food importing countries from price spikes and deterioration of their terms of trade and to protect poor food-buying households against erosion of their incomes.

- **Empowering poor rural agricultural communities:** Policies must enable and engage poor rural producers in biofuels development. Apart from providing the necessary credit and physical infrastructure, the poor and marginal rural producers also need support that ensures continued access to natural resources and secured land rights as well as access to agricultural technologies.
- **Promoting second-generation technologies:** The analysis presented in this study and also confirmed by several other recent studies, second-generation technologies and feedstocks may help overcome the risks and negative impacts of current biofuels chains. While second-generation biofuels technologies are still uncertain and under development, current biofuels based on sustainable sugar cane production or produced from recycled waste and residues hardly compete with food commodities and are also highly efficient in terms of greenhouse gas savings. Hence, until large scale deployment of second-generation technologies is technically. environmentally and economically proven, support policies should focus on forms of biofuels production that is environmentally, socially and economically viable.
- **Establishing sustainability criteria and best land use practices:** Expanding biofuels production is creating a growing environmental footprint. Environmental sustainability must clearly be accepted as 'sine qua non' condition of biofuels development. There is a large and growing body of understanding to guide land use practices and regulation which, when implemented and enforced, can avoid pitfalls and environmental disasters, both with regard to carbon emissions as well as biodiversity losses. While policies focused on biofuels feedstocks alone may contribute to protecting high-value ecosystems and carbon-rich land, it is obvious that such partial approaches would hardly avoid indirect land use effects and much larger positive impacts could be achieved if best practices and sustainability criteria are agreed and extended to all agricultural activities and land use.
- **Fostering equitable partnerships:** International cooperation and policy coordination is essential for sustainable biofuels expansion. While it is essential to create an efficient and enabling environment for investment in biofuels, it is even more so to counter risks of environmental damages and social exclusion that may derive from narrow self interest biofuels development objectives. Both international partnerships as well as mutually beneficial local community and private sector partnerships will need to be well designed to ensure commitments and equitably shared benefits.

The above policy considerations are critical to avoid the pitfalls due to hasty biofuels development and are relevant to ensuring that biofuels contribute to broad-based rural and agricultural development. Even then, liquid transport biofuels can only be expected to make a relatively small contribution to total energy supplies and are only one among many sources of renewable energy and their efficiency and societal value needs to be assessed vis-à-vis other current and future energy options in the context of comprehensive national and global energy strategies.

For more than thirty years there have been countless debates on the concerns of feeding cereals to livestock in a world where over one-sixth of the population has lived with chronic hunger and debilitating poverty. There is a risk that we might end up for the next thirty years debating the fallacy of feeding cereals to cars. This time the situation though is different as the entire world's population will be affected if we fail to deal with the challenges of providing clean energy, ensuring food security and coping with climate change, all of which are interrelated and need to be tackled together.

Annex: **Potentials for Main Biofuel Feedstocks**

Annex I

Global potentials for sugar cane

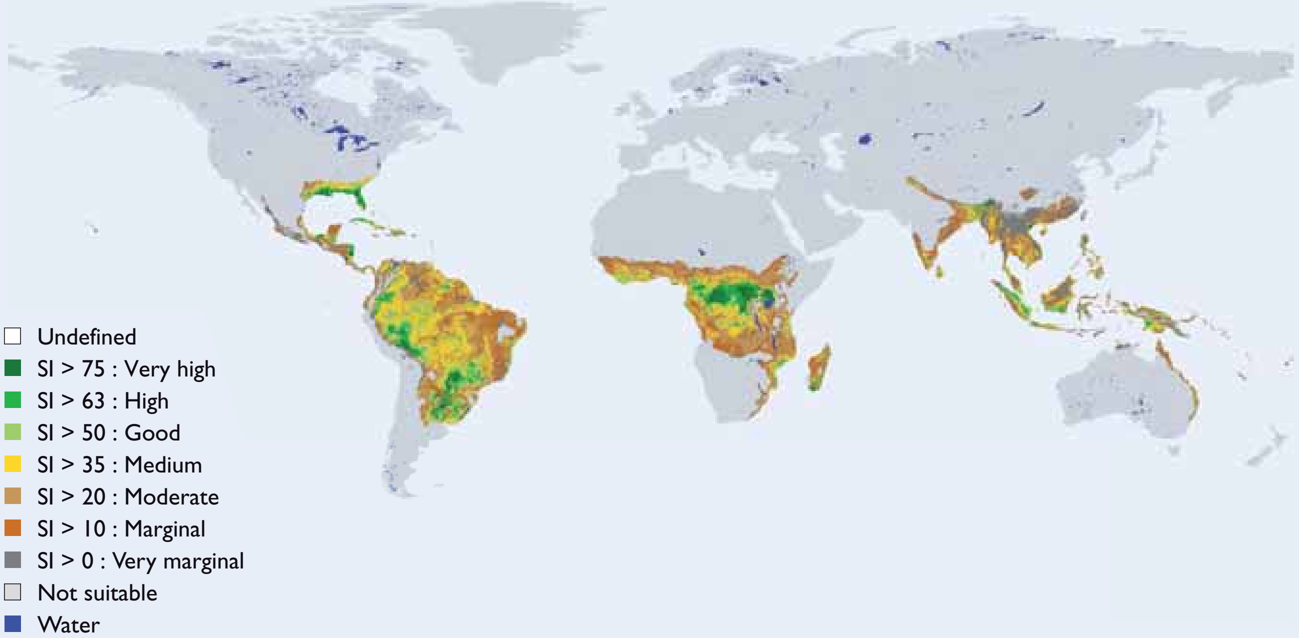
Sugar cane (*Saccharum officinarum*) belongs to the crops with a C4 photosynthetic pathway; it is adapted to perform best under conditions of relatively high temperatures and, in comparison to C3 pathway crops, has high rates of CO_2 exchange and photosynthesis, in particular at higher light intensities.

Sugar cane is a perennial with determinate growth habit; its yield is located in the stem as sucrose and the yield formation period is about two-thirds to three-quarters of its cultivated life span. Climatic adaptability attributes of sugar cane qualify it as being most effective in sub-humid and humid tropical lowland and warm subtropics. It does particularly well in semi-arid zones under irrigation, but is sensitive to frost. A short, dry, and moderately cool period at the end of its cultivation cycle significantly increases sugar content at harvest. Good commercial yields vary between 110 and 150 tons of fresh cane per hectare.

Ecological requirements of sugar cane include warm, sunny conditions and adequate soil moisture supply during most of its cultivation cycle. Sugar cane prefers deep, well drained, well structured, and aerated loamy to clayey fertile soils. Ideal pH range is 5.5–7.5.

Figure A.1 presents a map of agro-ecological suitability for rain-fed conditions. According to the AEZ assessment, most suitable areas are located in the southeastern parts of South America, e.g. including São Paulo State in Brazil, but also large areas in Central Africa, as well as some regions in Southeast Asia. Note

Global suitability for rain-fed sugar cane Figure A I



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed sugar cane Table A1-1

REGIONS *(Land: Mha)*	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND Very- and Suitable	POTENTIALLY SUITABLE LAND Moderately Suitable	HARVESTED AREA 2007
North America	230	8	7	0.4
Europe & Russia	305	0	0	0.0
Oceania & Polynesia	53	1	0	0.5
Asia	559	41	56	9.7
Africa	244	29	28	1.6
Central America	43	10	6	1.8
South America	129	46	32	8.0
Developed	591	9	8	0.8
Developing	972	126	122	21.2
World	1563	135	130	22.0
Brazil	66	30	20	6.7
Indonesia	35	17	11	0.4
Congo, Dem.R.	16	9	4	0.0
United States	179	8	7	0.4
Argentina	29	7	3	0.3

Source: Fischer et al., 2008; FAOSTAT, 2008.

that in India and Pakistan, the world's second and fifth largest producers of sugar cane, irrigation is needed to exploit thermal and radiation resources for sugar cane cultivation.

Table A1-1 summarizes by region, and for selected countries, the current distribution of cultivated land, its suitability for sugar cane, and the harvested area of sugar cane in 2007. Of the 1563 million hectares of cultivated land in 2007, 22 million hectares was used for sugar cane production, while the AEZ assessments show that 135 million hectares of this cultivated land are very suitable or suitable for rain-fed sugar cane, and an additional 130 million hectares moderately suitable.

Approximately 85 percent of the very suitable and suitable cultivated land is located in Africa (29 million ha), Asia (41 million ha), and South America (46 million ha) with 30 million hectares in Brazil alone.

The AEZ assessment of rain-fed sugar cane suitability in current unprotected grassland and woodland (Table A1-2) estimates that globally 87 million hectares would be very suitable or suitable, of which 26 million hectares are located in Africa and 54 million hectares in South America. There is only very limited potential (2 million hectares) in Asia, as most of the vast grassland resources of Central Asia are too cold and dry for rain-fed sugar cane production.

While legally protected areas, both forests and non-forest ecosystems, are less exposed to conversion, unprotected forest areas with good suitability for rain-fed sugar cane cultivation are of particular concern due to possible severe

Suitability of grassland/wood land for rain-fed sugar cane

Table A1-2

REGIONS (Land: Mha)	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	452	1	1
Europe & Russia	459	0	0
Oceania & Polynesia	496	1	1
Asia	511	2	5
Africa	878	26	44
Central Amer.& Carib.	71	2	2
South America	541	54	87
Developed	1400	2	2
Developing	2007	85	139
World	3408	87	141
Brazil	226	30	53
Congo, Dem.Rep.	163	12	5
Argentina	38	6	4
Colombia	26	6	9
Indonesia	9	4	1

Source: Fischer et al., 2008.

Suitability of forest land for rain-fed sugar cane

Table A1-3

REGIONS (Land: Mha)	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	434	13	13
Europe & Russia	819	0	0
Oceania & Polynesia	98	6	7
Asia	394	16	28
Africa	362	98	63
Central America	69	5	3
South America	629	89	246
Developed	1341	15	14
Developing	1465	213	346
World	2806	228	360
Congo, Dem.R.	130	62	29
Brazil	378	41	167
Peru	54	15	20
United States	175	13	13
Indonesia	74	12	17

Source: Fischer et al., 2008;.

environmental impacts. The AEZ methodology was therefore used to assess the magnitude and geographical distribution of suitability of current unprotected forest areas for rain-fed sugar cane production. (Table A1-3).

In total, 2.8 billion hectares of land globally are classified as unprotected forests, of which 8 percent (228 million hectares) were assessed as being either very suitable or suitable for sugar cane. More than 80 percent of the very suitable and suitable unprotected forestland is located in Africa (98 million hectares) and South America (89 million hectares). The Democratic Republic of Congo alone has 130 million hectares of unprotected forest of which close to half is either very suitable or suitable for sugar cane.

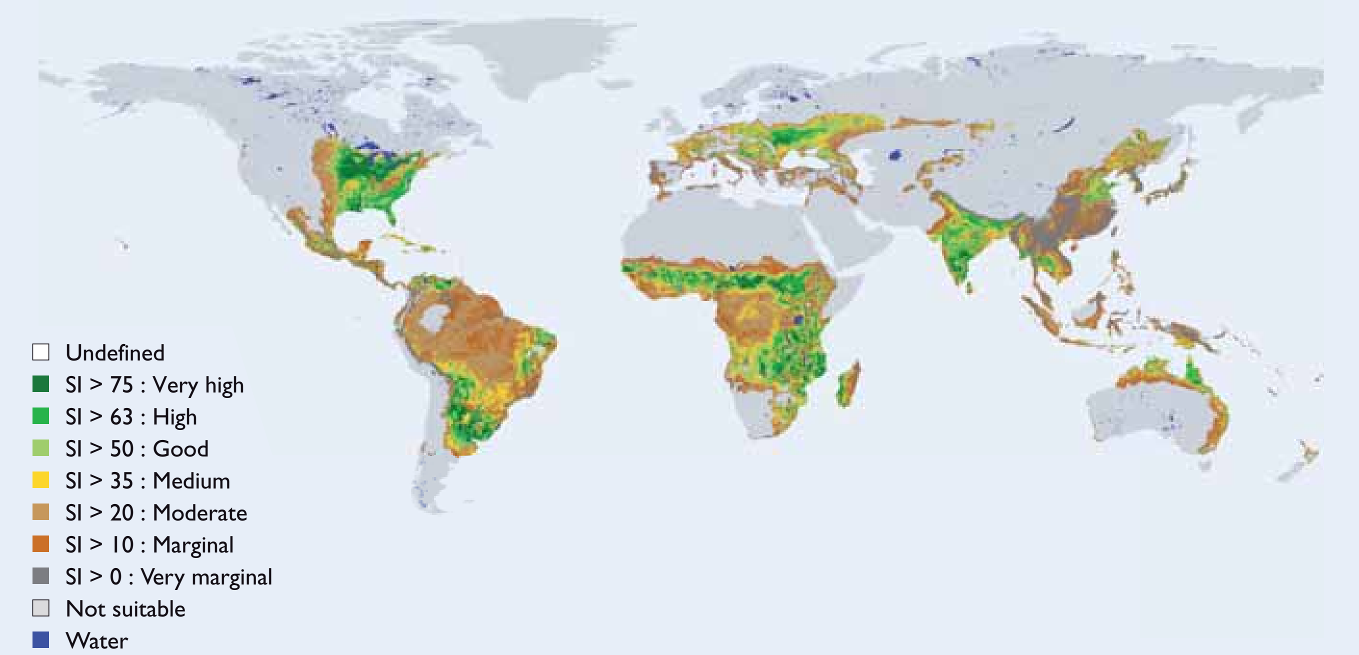
Annex 2

Global potentials for maize

Maize (*Zea mays*) is also a C4 crop; it is well adapted to perform under conditions of high temperatures and short day-lengths (tropical varieties) as well as in moderately cool temperatures and longer day-lengths (subtropical/temperate varieties). In comparison to C3 pathway crops, maize has substantially higher rates of CO_2 exchange and photosynthesis, in particular at higher light intensities. Biomass, as well as grain yields, are superior to C3 cereals.

Maize is an annual with determinate growth habit; its yield is located in cobs on modified lateral branches and the yield formation period is about one-third of its cultivated

Global suitability for rain-fed Maize Figure A2



Fischer et al., 2008a.

life cycle. Good commercial maize yields vary between 8 and 10 tons of grain per hectare

Ecological requirements of maize are supported by a range of thermal conditions from hot to moderately cool. High maize yields require sunny conditions and adequate soil moisture supply during most of its cultivation cycle. Maize is susceptible to salinity, sodicity, excess calcium carbonate and gypsum, and has low tolerance to waterlogging and high groundwater tables. It prefers moderately deep to deep, well drained, well structured, and aerated loamy to clayey fertile soils. Ideal pH range is 5.8–7.8.

Figure A2 presents a map of agro-ecological suitability for rain-fed conditions. Suitable conditions are widely distributed over tropical, subtropical, and temperate zones with moist semi-arid or better soil moisture regimes. Very wet areas cause pest and disease problems as well as workability constraints affecting yields. Dry semi-arid conditions only allow short cycle varieties with relative low productivity. Although almost entirely grown under rain-fed conditions, maize is highly suitable for production under various irrigation systems.

Table A2-1 summarizes by region, and for selected countries, the current distribution of cultivated land, its suitability for maize, and the harvested area of maize in 2007.

Of the 1563 million hectares of cultivated land in 2007, approximately 160 million

Suitability of cultivated land for rain-fed maize Table A2 - 1

REGIONS *(Land: Mha)*	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND Very- and Suitable	POTENTIALLY SUITABLE LAND Moderately Suitable	HARVESTED AREA 2007
North America	230	103	28	36.4
Europe & Russia	305	49	84	13.9
Oceania & Polynesia	53	2	3	0.1
Asia	559	156	125	48.8
Africa	244	113	54	29.0
Central America	43	13	13	10.0
South America	129	42	38	19.7
Developed	591	154	116	50.4
Developing	972	324	229	107.5
World	1563	478	345	157.9
United States	179	99	26	35.0
India	167	96	38	7.8
China	139	34	45	28.1
Nigeria	35	21	7	4.7
Argentina	29	20	5	2.8
Brazil	66	10	26	13.8

Source: Fischer et al., 2008a; FAOSTAT, 2008.

Suitability of grassland/woodland for rain-fed maize Table A2 - 2

REGIONS *(Land: Mha)*	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND Very- and Suitable	 Moderately Suitable
North America	452	2	5
Europe & Russia	459	5	8
Oceania & Polynesia	496	27	23
Asia	511	4	14
Africa	878	211	115
Central America	71	3	7
South America	541	78	76
Developed	1400	33	35
Developing	2007	297	212
World	3408	330	247
Sudan	98	48	12
Brazil	226	27	46
Australia	479	26	21
Argentina	163	26	9
Mozambique	39	23	7

Source: Fischer et al., 2008a.

hectares was harvested for maize. The AEZ assessments show that 478 million hectares of the global cultivated land are very suitable or suitable for rain-fed maize and an additional 345 million hectares moderately suitable.

More than 70 percent of the very suitable and suitable cultivated land is located in Asia (156 million ha), Africa (113 million ha), and North America (103 million ha), with 99 million hectares in the USA alone.

It is interesting to note that China and Brazil apparently utilize a significant portion of their potentially available very suitable and suitable land for maize production. In Brazil, 10 million hectares are very suitable or suitable from an agro-ecological point of view compared to 14 million hectares harvested in 2007. Among the principal maize producers, only the USA would have significantly more suitable areas for maize production compared to their current harvest of 35 million hectares. However, any extensions in maize areas will be at the expense of other agricultural commodities.

Table A2-1 indicates that in many parts of the world additional cultivated land could potentially be transferred to maize production. The exception is South and Central America. The largest differences in cultivated land areas suitable for maize production and actual maize harvests (i.e. potentials for additional maize production) are located in Asia, Africa, and North America.

Tables A2-2 and A2-3 summarize, for different regions and countries, the suitability of

Suitability of forest land for rain-fed maize Table A2 - 3

REGIONS (Land: Mha)	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND Very- and Suitable	Moderately Suitable
North America	434	61	34
Europe & Russia	819	8	16
Oceania & Polynesia	98	13	11
Asia	394	17	18
Africa	362	55	85
Central America	69	8	6
South America	629	40	55
Developed	1341	81	60
Developing	1465	121	165
World	2806	202	225
United States	175	59	33
Congo, Dem.R.	130	14	28
Argentina	23	13	1
Australia	64	12	9
India	46	10	6

Source: Fischer et al., 2008a; calculation by authors.

currently unprotected grassland, woodland, and forestland for rain-fed grain maize production. Globally, almost ten percent of total grassland and woodland or 330 million hectares is very suitable or suitable for maize production. More than half of this is located in Africa.

Land use conversion from forest to arable land entails substantial carbon debts and deforestation should be avoided from a greenhouse gas perspective. In addition, deforestation is a prime cause for loss of biodiversity. Table A2-3 can thus be interpreted as regions at high risk of undesirable conversion due to its suitability for maize expansion. In the United States of America, Australia, India, Argentina, and Africa a substantial share of their forestland would be suitable for maize cultivation.

Annex 3

Global potentials for cassava

Cassava (*Manihot esculenta*) is a C3 crop adapted to perform best in tropical lowland conditions. It produces yields across a range of moisture regimes from semi-arid to per-humid (i.e., 500–5000 mm annual rainfall).

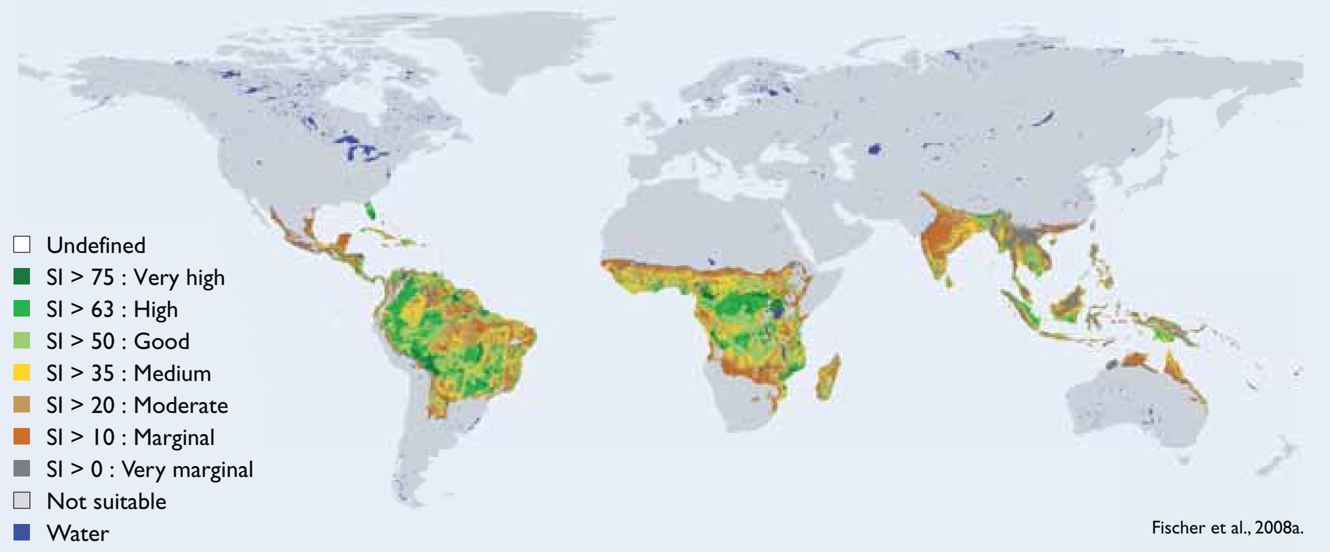
Cassava is a short-term perennial grown as an annual crop, with an indeterminate growth habit; yield (tuber/starch) is located in the roots with the yield formation period coinciding with much, or all, of its life span. Climatic adaptability attributes of cassava qualify it being most effective in tropical lowland climates (short day photoperiodic conditions). Good commercial yields of fresh roots vary between 35 to more than 50 tons per hectare

Ecological requirements of cassava are modest in terms of soil fertility and moisture supply. Cassava can be grown on soils with low fertility. On very fertile soils the vegetative growth of cassava is very luxurious at the expense of the roots. Cassava is very sensitive to salinity, prefers moderately deep soils that are at least moderately well drained. Cassava is sensitive to waterlogging and no flooding should occur. Optimum pH range is 5.2–7.0.

An aggressive strain of a virus called Cassava Mosaic Disease (CMD) has decimated harvests throughout Africa, with disastrous food security consequences.. The International Institute of Tropical Agriculture (IITA) in Nigeria, through its cassava breeding and selection program, has produced a series of disease-free varieties. These varieties were multiplied in nurseries of national research institutions, local governments, and civil society, and eventually produced adequate amounts of planting material for massive re-introduction in Central Africa.

Figure A3 presents a map of agro-ecological suitability for rain-fed conditions. The best ecological conditions are located in sub-humid and humid tropical lowland zones. Due to its drought resistance and resilience, cassava is distributed widely in semi-arid zones as well.

Global suitability for rain-fed cassava Figure A3



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed cassava

Table A3 - 1

REGIONS (Land: Mha)	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND		HARVESTED AREA 2007
		Very- and Suitable	Moderately Suitable	
North America	230	3	0	0.0
Europe & Russia	305	0	0	0.0
Oceania & Polynesia	53	1	1	0.0
Asia	559	74	69	3.8
Africa	244	68	31	11.9
Central America	43	10	9	0.2
South America	129	58	21	2.7
Developed	591	3	1	0.0
Developing	972	210	130	18.7
World	1563	213	131	18.7
Brazil	66	42	15	1.9
Indonesia	35	19	9	1.2
Congo, Dem.R.	16	13	1	1.9
Thailand	19	11	6	1.2
India	167	11	37	0.2

Source: Fischer et al., 2008a; FAOSTAT, 2008.

Suitability of grassland/woodland for rain-fed cassava

Table A3 - 2

REGIONS (Land: Mha)	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	452	1	0
Europe & Russia	459	0	0
Oceania & Polynesia	496	2	6
Asia	511	5	6
Africa	878	80	108
Central America	71	2	2
South America	541	97	81
Developed	1400	2	5
Developing	2007	184	198
World	3408	186	203
Brazil	226	61	63
Colombia	28	15	2
Mozambique	39	12	12
Congo, Dem.R.	26	11	12
Sudan	98	11	8

Source: Fischer et al., 2008a.

Suitability of forest land for rain-fed cassava Table A3 - 3

REGIONS *(Land: Mha)*	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND Very- and Suitable	 Moderately Suitable
North America	434	1	1
Europe & Russia	819	0	0
Oceania & Polynesia	98	8	10
Asia	394	24	33
Africa	362	146	102
Central America	69	5	4
South America	629	215	148
Developed	1341	3	6
Developing	1465	396	292
World	2806	399	298
Brazil	378	115	95
Congo, Dem.R.	130	74	41
Peru	54	33	7
Bolivia	42	27	7
Colombia	44	17	11

Source: Fischer et al., 2008a;.

Table A3-1 summarizes by region, and for selected countries, the current distribution of cultivated land, the land harvested for cassava in 2007, and the area of current cultivated land assessed as very suitable, suitable, and moderately suitable. Globally, the currently harvested 19 million hectares of land for cassava compare to a potential of 213 million hectares very suitable or suitable land, and another potential 131 million hectares of moderately suitable land.

More than 90 percent of the very suitable or suitable land, within the current cultivated land is located in Asia (74 million hectares), Africa (68 million hectares), and South America (58 million hectares).

A potential area of very suitable and suitable land for cassava cultivation twice as large as currently cultivated land is located in currently unprotected forestland, an estimated 399 million hectares. Africa accounts for 146 million hectares of this potential and South America for 215 million hectares of which Brazil has 115 million hectares alone (Table A3.3). Furthermore, land currently under unprotected grassland and woodland ecosystems globally include 186 million hectares that are very suitable or suitable for cassava. (Table A3.2). These grassland and woodland ecosystem predominantly correspond to 'cerrado' areas in Brazil. At least part of these cerrado areas are known for their complex natural ecosystems with high biodiversity. In Brazil, 61 million hectares, or more than 25 percent, of these ecosystems are very suitable or suitable for rain-fed cassava production.

Annex 4

Global potentials for rapeseed

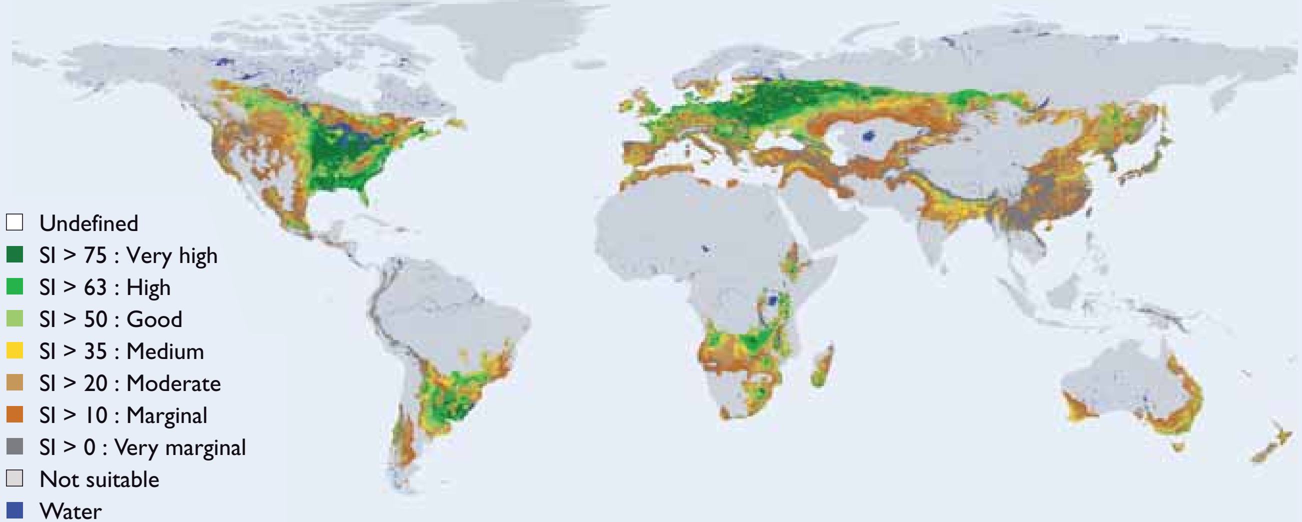
Rape (*Brassica napus*) is a C3 crop adapted to perform under moderately cool and cool conditions. Rapeseed is grown as a *winter crop* with hibernation period, as a *spring crop* in areas where winter temperatures are too cold for survival of winter rape, and as cultivars grown in the cool season in subtropical areas including the border areas between the subtropics and tropics. These latter types are widely grown in South Asia and are locally referred to as *rabi rape*.

Breeding has developed a large number of rape varieties that are well adapted to specific local conditions, e.g., varying growth cycle lengths and improved resistance to diseases associated with prolonged humid conditions. In addition, the harvest index (share of seed in total biomass production) has been substantially enhanced through selective breeding and harvest losses have decreased through improved harvest technologies. Good commercial rape yields vary between 3 and 4 tons of seed per hectare

Ecological requirements of rape include a sufficiently long period of moderately cool and cool temperatures to secure proper phenological development. Prolonged periods of high temperatures depress photosynthesis and growth. High rapeseed yields require high levels of fertilization with appropriate timing and dosing, and adequate soil moisture supply during the entire cultivation cycle. Rape is susceptible to salinity, sodicity, excess calcium carbonate and gypsum, and has low tolerance to water logging. Rape prefers deep, well drained, well structured, loamy to clayey fertile soils. Ideal pH range is 5.6–7.0.

Figure A4 presents a map of agro-ecological suitability for rain-fed conditions. Suitable conditions are widely distributed over temperate and subtropical zones. Very wet areas cause disease problems as well as workability constraints affecting obtained yields. Water scarcity during the growing period, and areas with only very short periods with

Global suitability for rain-fed rapeseed Figure A4



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed rapeseed Table A4 - 1

REGIONS *(Land: Mha)*	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND Very- and Suitable	Moderately Suitable	HARVESTED AREA 2007
North America	230	132	49	6.3
Europe & Russia	305	160	81	8.2
Oceania & Polynesia	53	10	10	1.1
Asia	559	45	122	14.5
Africa	244	39	19	0.1
Central America	43	5	3	0.0
South America	129	45	15	0.1
Developed	591	303	142	15.6
Developing	972	134	157	14.7
World	1563	436	299	30.2
United States	179	116	32	0.5
Russia, Fed.Rep	126	56	44	0.5
China	139	28	41	7.1
Argentina	29	22	4	0.0
Ukraine	33	18	15	1.0
Canada	52	16	17	5.8
Brazil	66	15	9	0.0
Poland	14	14	0	0.8
France	20	14	1	1.6
South Africa	16	9	4	0.0
EU27	128	73	20	6.5

Source: Fischer et al., 2008a; FAOSTAT, 2008.

moderately cool and cool conditions, at best allow short cycle varieties with relative low productivity. Although mainly grown as rainfed crop, rape is also produced under irrigated conditions.

In 2007, 30 million hectares of cultivated land were harvested for rapeseed, half of it in Asia. However, over two-thirds of potentially very suitable or suitable areas in cultivated land are located in Europe and Russia with 160 million hectares and North America with 132 million hectares. The USA alone has 116 million hectares of potentially suitable land out of a total of 179 million hectares of cultivated land (Table A4-1).

Potentials in unprotected grassland and woodland are significantly lower than in cultivated land. Only five percent is very suitable or suitable for rapeseed (Table A4-2). In unprotected forestland this share is greater than 10 percent. The Russian Federation has the highest potential with 100 million hectares, or approximately 15 percent of its unprotected forestland (Table A4-3).

Suitability of grassland/woodland for rain-fed rapeseed

Table A4 - 2

REGIONS *(Land: Mha)*	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	452	7	25
Europe & Russia	459	24	21
Oceania & Polynesia	496	4	8
Asia	511	7	31
Africa	878	50	42
Central America	71	3	4
South America	541	63	40
Developed	1400	35	54
Developing	2007	122	116
World	3408	158	170
Argentina	163	24	14
Brazil	226	24	21
Russia, Fed.Rep	372	10	11
Uruguay	13	10	1
Zambia	19	8	4

Source: Fischer et al., 2008a.

Suitability of forest land for rain-fed rapeseed

Table A4 - 3

REGIONS *(Land: Mha)*	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	434	118	50
Europe & Russia	819	119	35
Oceania & Polynesia	98	9	8
Asia	394	15	14
Africa	362	34	25
Central America	69	5	2
South America	629	20	19
Developed	1341	247	95
Developing	1465	74	58
World	2806	321	153
Russia, Fed.Rep	678	100	26
United States	175	92	12
Canada	259	26	39
China	128	13	4
Zambia	18	12	2

Source: Fischer et al., 2008a; calculation by authors.

Annex 5

Global potentials for oil palm

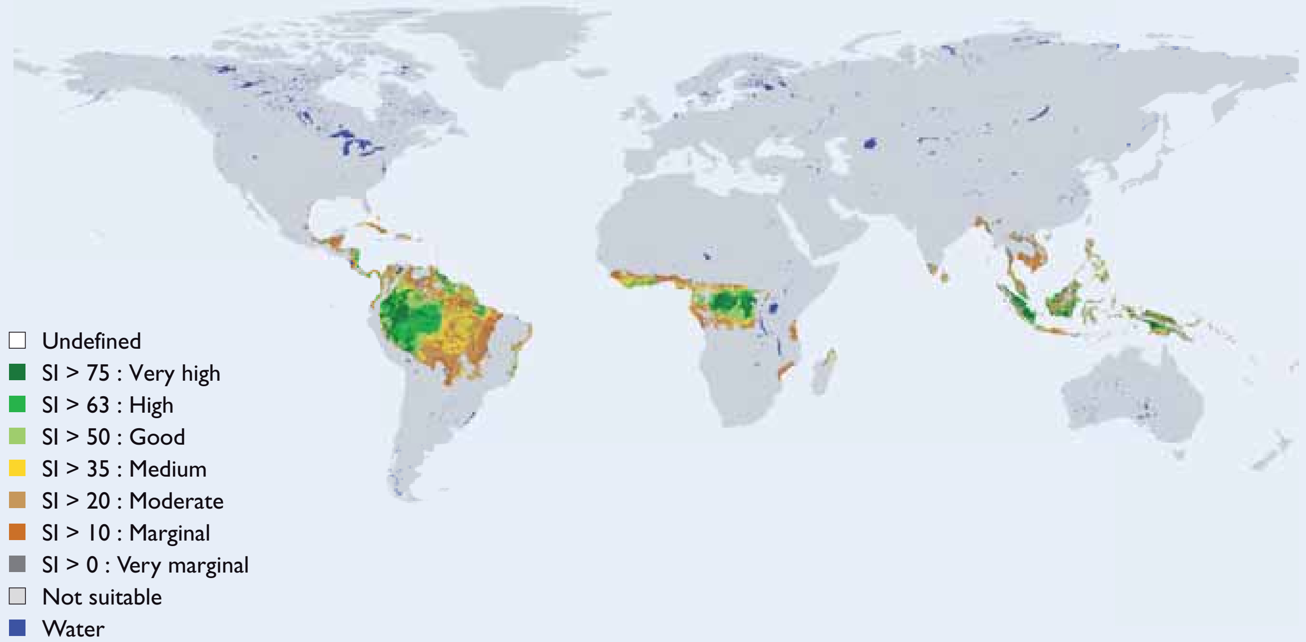
Oil palm (*Elaeis guineensis*) is a C3 crop adapted to perform best under conditions of warm temperatures and more than 1300 annual sunshine hours. Oil palm performs best in humid tropical conditions.

Oil Palm is a perennial with indeterminate growth habit; its yield is located in lateral inflorescences and the yield formation period coincides almost with its entire life span. Climatic adaptability attributes of oil palm qualify it as being most effective in equatorial tropical lowland climates. Good commercial yields vary between 5 and 7 tons of oil per hectare.

Ecological requirements of oil palm include warm, sunny conditions high air humidity and generous soil moisture supply. Oil palm is very sensitive to salinity, does not tolerate poorly drained soils with ironstone gravel, sandy coastal soils, or deep peat soils. Potassium is the main nutrient required and nitrogen is needed for rapid growth of young palms. Available phosphorous and exchangeable potassium should be high. However, palm oil is very sensitive to excess calcium carbonate and gypsum. Oil palm prefers deep, permeable, well structured, and clay to clay-loam soils. Optimum pH range is 5.0–6.5.

Figure A5 presents a map of agro-ecological suitability for rain-fed conditions. The best ecological conditions are located in Southeast Asia, parts of South America, and equatorial West and Central Africa. Extreme wet areas, such as those in parts of the Amazon basin produce significantly lower yields due to decreases in both pollen density and oil content of the mesocarp. Oil palm is less suitable for irrigated production in drier climates because of its specific air humidity requirements.

Global suitability for rain-fed oil palm Figure A5



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed oil palm Table A5 - 1

REGIONS (Land: Mha)	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND		HARVESTED AREA 2007
		Very- and Suitable	Moderately Suitable	
North America	230	0	0	0.0
Europe & Russia	305	0	0	0.0
Oceania & Polynesia	53	1	0	0.1
Asia	559	37	8	8.9
Africa	244	10	9	4.3
Central America	43	3	3	0.2
South America	129	4	9	0.4
Developed	591	0	0	0.0
Developing	972	55	28	13.9
World	1563	55	28	13.9
Indonesia	35	23	2	4.6
Malaysia	8	6	0	3.8
Philippines	11	6	2	0.0
Congo, Dem.R.	16	4	2	0.2
Cote D'ivoire	9	3	2	0.2

Source: Fischer et al., 2008a; FAOSTAT, 2008.

Table A5-1 summarizes by region the current distribution of cultivated land, the land harvested for oil palm in 2007, and the area of current cultivated land assessed as very suitable or suitable land and moderately suitable land. In 2007, oil palm's harvested area globally comprised 14 million hectares. Of the current 1563 million hectares cultivated land only approximately 55 million hectares is very suitable or suitable for rain-fed oil palm cultivation, with almost all of this located in Africa (10 million hectares), Asia (37 million hectares), and South and Central America (7 million hectares). Suitable land in unprotected grassland and woodland ecosystems is almost non-existent. Less than one percent of those ecosystems is very suitable or suitable for oil palm production (Table A5-2).

A much larger potential in terms of very suitable and suitable land for palm oil cultivation is located in unprotected forestland, an estimated 324 million hectares, or almost six times the potential, of cultivated land (Table A5-3). This shows the potentially very high environmental risk associated with a surge in demand for palm oil as experienced recently.

Suitability of grassland/woodland for rain-fed oil palm

Table A5 - 2

REGIONS (Land: Mha)	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	452	0	0
Europe & Russia	459	0	0
Oceania & Polynesia	496	1	0
Asia	511	3	1
Africa	878	3	9
Central America	71	1	1
South America	541	6	18
Developed	1400	0	0
Developing	2007	14	30
World	3408	14	30
Colombia	28	3	8
Indonesia	9	3	1
Brazil	226	2	7
Pap N Guin	6	1	0
Liberia	4	1	1

Source: Fischer et al., 2008a.

Suitability of forest land for rain-fed oil palm

Table A5 - 3

REGIONS (Land: Mha)	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	434	0	0
Europe & Russia	819	0	0
Oceania & Polynesia	98	9	2
Asia	394	36	8
Africa	362	70	34
Central America	69	4	2
South America	629	198	126
Developed	1341	0	0
Developing	1465	317	173
World	2806	317	173
Brazil	378	108	101
Congo, Dem.R.	130	52	21
Peru	54	37	3
Indonesia	74	29	6
Colombia	44	25	5

Source: Fischer et al., 2008a; calculation by authors.

Annex 6

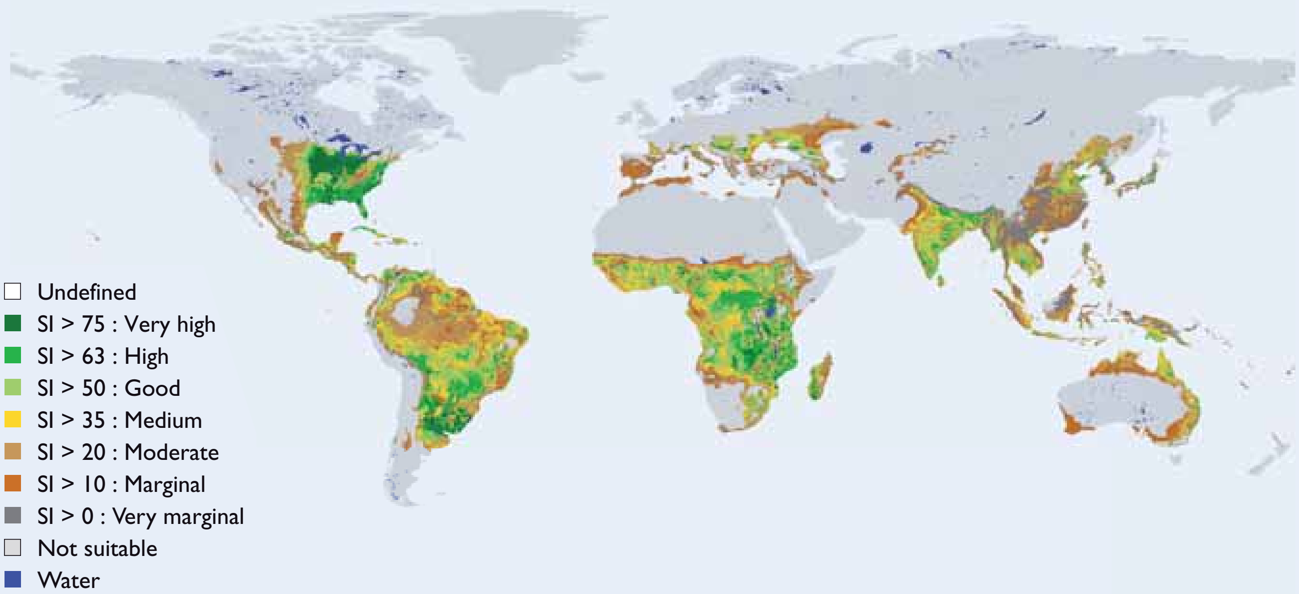
Global potentials for soybean

Soybean (*Glycine max*) is a C3 crop adapted to perform under warm to moderately cool conditions. Soybean's wide climatic adaptability spectrum makes it possible for it to be grown across a range of thermal regimes, ranging from tropical to subtropical and temperate zones with warm summers, and across moisture regimes ranging from semi-arid to humid.

Breeding has developed a large number of soybean cultivars that are well adapted to specific local conditions, e.g., varying growth cycle lengths and improved resistance to diseases associated with prolonged humid conditions. Also the harvest index (share of seed in total biomass production) has been substantially enhanced. Good commercial soybean yields vary between 3.5 and 4.5 tons of grain per hectare. At present, GM soybeans yields are reported to exceed 5 tons per hectare. These yields are achieved in large scale enterprises in Brazil and Argentina.

Ecological requirements of soybean include moderately warm and warm temperatures for photosynthesis and growth and adequate soil moisture supply during the entire cultivation cycle. (During part of its growth cycle it tolerates moderately cool temperatures). Soybean can be grown on a wide variety of soils. However, high soybean yields require high levels of fertilization and use of agro-chemicals to deal with competition of weeds and combat pest and diseases. Soybean is susceptible to salinity, sodicity, excess calcium carbonate and gypsum, and has low tolerance to waterlogging. Soybean prefers deep, well drained, well structured, loamy to clayey fertile soils. Ideal pH range is 5.5–7.5.

Global suitability for rain-fed soybean Figure A6



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed soybean Table A6 - 1

REGIONS *(Land: Mha)*	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND Very- and Suitable	Moderately Suitable	HARVESTED AREA 2007
North America	230	103	24	31.7
Europe & Russia	305	17	37	2.0
Oceania & Polynesia	53	2	5	0.0
Asia	559	149	145	19.4
Africa	244	122	48	1.3
Central America	43	17	11	0.1
South America	129	87	23	40.4
Developed	591	124	66	33.7
Developing	972	373	228	61.2
World	1563	498	294	94.9
United States	179	103	24	30.6
India	167	65	60	8.6
Brazil	66	48	14	20.6
China	139	38	39	8.9
Argentina	29	22	4	16.1
EU27	128	7	11	0.4

Source: Fischer et al., 2008a; FAOSTAT, 2008.

Figure A6-1 presents a map of agro-ecological suitability for rain-fed conditions. Suitable conditions are widely distributed over temperate, subtropical, and tropical zones. Very wet conditions cause disease problems as well as workability constraints affecting obtained yields. Prolonged dry spells during the growing period and areas with only short periods of moderately warm to warm conditions, at best, allow less productive short cycle cultivars.

Although mainly grown as rain-fed crop, soybean is successfully produced under irrigated conditions.

Transgenic roundup-resistant soybean varieties have been developed and released and are used on large scales in Argentina, Brazil and the USA. In addition to their resistance to round-up, the GM cultivars have substantial yield advantages.

Table A6-1 shows that about one-third of the cultivated land is very suitability or suitable for soybean cultivation. Larges potentials are found in Asia (China and India), South America (Brazil and Argentina), and in the USA where almost half of its cultivated land is very suitable or suitable for soybean production.

The suitability assessment of unprotected grassland and woodland reveals that ample land in Africa with 194 million hectares and South America (e.g., cerrado area in Brazil) with 131 million hectares is either very suitable or suitable for soybean (Table A6-2).

Similarly, unprotected forestland is to a large extent potentially suitable for soybean.

Suitability of grassland/wood land for rain-fed soybean

Table A6 - 2

REGIONS *(Land: Mha)*	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND Very- and Suitable	 Moderately Suitable
North America	452	4	13
Europe & Russia	459	1	3
Oceania & Polynesia	496	9	29
Asia	511	5	14
Africa	878	194	152
Central America	71	4	6
South America	541	131	117
Developed	1400	14	44
Developing	2007	335	290
World	3408	348	334
Brazil	226	72	72
Argentina	163	28	12
Mozambique	39	23	6
Sudan	98	22	33
Tanzania	33	17	5

Source: Fischer et al., 2008a.

Suitability of forest land for rain-fed soybean

Table A6 - 3

REGIONS *(Land: Mha)*	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND Very- and Suitable	 Moderately Suitable
North America	434	68	14
Europe & Russia	819	1	2
Oceania & Polynesia	98	9	17
Asia	394	18	30
Africa	362	145	124
Central America	69	7	8
South America	629	81	176
Developed	1341	77	28
Developing	1465	253	342
World	2806	329	370
Congo, Dem.R.	130	70	43
United States	175	68	14
Brazil	378	32	103
Bolivia	42	16	18
Angola	54	14	29

Source: Fischer et al., 2008a; calculation by authors.

The largest areas of very suitable and suitable land are located in Africa, with 145 million hectares, or approximately 40 percent, of its unprotected forest. In the Democratic Republic of Congo, almost 90 percent of its 130 million hectares under unprotected forest is either very suitable or suitable (70 million hectares), or is moderately suitable (43 million hectares). In South America 81 million hectares are very suitable and suitable and in the USA 68 million hectares.

Annex 7

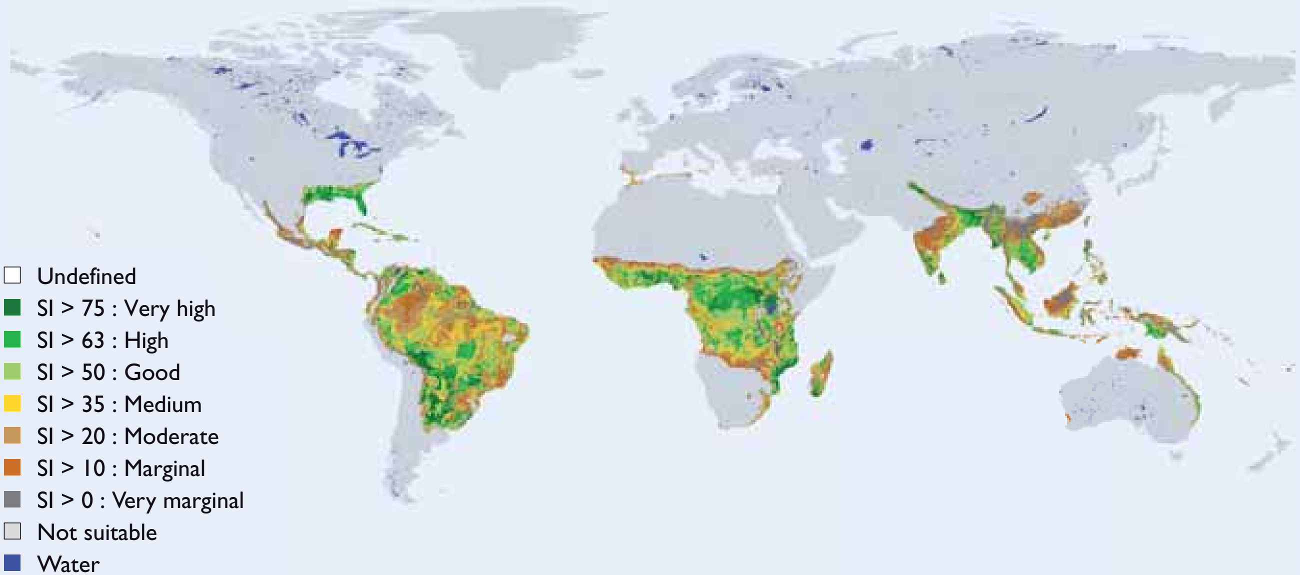
Global potentials for jatropha

Jatropha is a genus of approximately 175 succulent plants, shrubs and trees. *Jatropha curcas* is native to Central America and has become naturalized in many tropical and subtropical areas, including India, Africa, and North America. Originating in the Caribbean, jatropha was spread as a valuable hedge plant to Africa and Asia. As with many members of the family Euphorbiaceae, jatropha contains compounds that are highly toxic.

Jatropha, also referred to as Physic nut, is a C3 plant adapted to perform best under conditions of warm temperatures. It has moderate response to higher light intensities and relatively moderate rates of photosynthesis.

Jatropha is a perennial with indeterminate growth habit; its yield is located in lateral inflorescence with the yield formation period covering the greater fraction of its life span. Climatic adaptability attributes of jatropha qualify it as being most effective in tropical lowland climates. Recorded seed yields vary widely between 0.5 and 12 tons per hectare and show high variability in seed weight and oil content. Rotation lengths in plantations are approximately 20 years with maximum

Global suitability for rain-fed jatropha Figure A7



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed jatropha Table A7 - 1

REGIONS *(Land: Mha)*	TOTAL CULTIVATED LAND	POTENTIALLY SUITABLE LAND Very- and Suitable	Moderately Suitable	HARVESTED AREA 2007
North America	230	16	3	0.0
Europe & Russia	305	0	1	0.0
Oceania & Polynesia	53	2	1	0.0
Asia	559	117	51	1.8
Africa	244	81	22	0.1
Central America	43	15	9	0.0
South America	129	72	19	0.0
Developed	591	17	4	0.0
Developing	972	286	103	1.9
World	1563	303	107	1.9
Brazil	66	43	13	0.0
India	167	36	14	0.5
United States	179	16	3	0.0
Thailand	19	16	3	0.0
Indonesia	35	15	13	0.2
Congo, Dem. R.	16	14	1	0.0
Argentina	29	11	2	0.0
Myanmar	12	9	1	0.9
Nigeria	35	9	4	0.0
China	139	8	9	0.2
EU27	128	8	1	0.0

Source: Fischer et al., 2008a; FAOSTAT, 2008.

yields obtained after four to six years. After that, yields may be reduced due mainly to pest and disease problems.

Ecological requirements of jatropha include warm semi-arid to sub-humid tropical conditions (quite similar to cassava). Jatropha is reported as being a hardy, drought tolerant plant, and highly water use efficient. In fact, short dry periods induce flowering and benefits yields. Jatropha prefers deep well aerated sandy loam soils, it does not tolerate flooding and waterlogged conditions. Although it has low nutrient requirements, grows well on marginal soils, and tolerates saline conditions, jatropha responds well to organic matter and chemical fertilizer. Jatropha does not tolerate vertic soil conditions associated with montmorillonite clay types. Optimum pH range is 6–8.

Generally, jatropha is tolerant or resistant to pests and diseases, however under humid conditions serious problems with fungi, viruses, and insect attacks are recorded. Collar rot occurs in juvenile stages and during periods with waterlogging. Other problems are leaf spots and root rot, while pruning might trigger fungal and bacterial infection. All pest and

Suitability of grassland/woodland for rain-fed jatropha Table A7 - 2

REGIONS (Land: Mha)	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	452	3	2
Europe & Russia	459	0	0
Oceania & Polynesia	496	4	4
Asia	511	9	9
Africa	878	123	96
Central America	71	3	3
South America	541	127	83
Developed	1400	6	5
Developing	2007	264	193
World	3408	269	198
Brazil	226	67	56
Argentina	163	17	10
Mozambique	39	16	8
Madagascar	38	15	5
Sudan	98	14	13
Congo, Dem. R.	28	13	10
Cent. Afr. Rep.	28	13	4
Colombia	26	12	10
Venezuela	26	10	8
Tanzania	33	10	8

Source: Fischer et al., 2008a.

diseases are claimed to be controllable, although with high input use.

In humid areas, where jatropha produces flowers in sequence, mechanical harvesting of jatropha nuts, while preserving new flowers, causes mechanical harvesting problems.

Globally, jatropha is rarely used for the commercial production of vegetable oil. FAOSTAT reports 1.9 million hectares while other sources quote 0.9 million hectares under plantation. Based on current knowledge of agronomic, environmental adaptability characteristics, and biophysical requirements, an attempt has been made to assess global potentials for jatropha.

Figure A7 presents a map of agro-ecological suitability for rain-fed conditions. Jatropha grows particularly well in West, Central, and East Africa, South Asia, Bolivia, Paraguay, Brazil and in the southern United States of America.

Results show that globally approximately 20 percent of cultivated areas are very suitable or suitable for jatropha with the largest potentials in located in Asia, Africa, and South America. Potentials for jatropha occur almost exclusively in developing countries. (Table A7-1)

Suitability of forest land for rain-fed jatropha Table A7 - 3

REGIONS *(Land: Mha)*	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND	
		Very- and Suitable	Moderately Suitable
North America	434	23	10
Europe & Russia	819	0	0
Oceania & Polynesia	98	10	9
Asia	394	28	32
Africa	362	164	94
Central America	69	5	6
South America	629	145	174
Developed	1341	28	14
Developing	1465	348	311
World	2806	376	324
Congo, Dem. R.	130	76	37
Brazil	378	62	122
Bolivia	42	27	8
United States	175	23	10
Angola	54	14	19
Peru	54	14	15
Cameroon	20	12	5
Congo	19	12	3
Argentina	23	10	5
Cent. Afr. Rep.	16	9	4

Source: Fischer et al., 2008a.

Jatropha is claimed to have high potential in savannah type areas. However, the results of the AEZ assessment show that globally only eight percent of the unprotected grassland and woodland is very suitable or suitable for jatropha. There is another six percent moderately suitable (Table A7-2). The largest extents of very suitable and suitable areas are found in Africa with 123 million hectares and in South America with 127 million hectares. By far the largest extents of very suitable and suitable land in a single country are found in Brazil's grassland and woodland ecosystems.

Globally, approximately 700 million hectares of all unprotected forestland would be very suitable, suitable or moderately suitable for jatropha (Table A7-3). When considering the largely tropical forests in developing countries, the share of the unprotected forestland that is very suitable or suitable for jatropha is approximately 45 percent. For instance, the unprotected forests in Central Africa, in particular in the Democratic Republic of Congo, are 60 percent very suitable or suitable for jatropha.

Annex 8

Global potentials for lignocellulosic feedstocks

Extensive use of biofuels requires expansion of the range of feedstocks and the introduction of advanced conversion technologies, such as Fischer-Tropsch synthesis of biodiesel and ethanol production from enzymatic conversion of lignocellulosic feedstocks.

Second-generation biofuel feedstocks include herbaceous lignocellulosic species, such as miscanthus, switchgrass, and reed canary grass, and woody lignocellulosic species including poplar, willow, and eucalypt.

Herbaceous lignocellulosic feedstocks

Important perennial grasses include switchgrass and miscanthus (highly productive C4 species and more cold tolerant than reed canary grass (a slightly less productive C3 species). Switchgrass especially is claimed to produce well on marginal sites. All three grasses are generally harvested once a year.

These perennial grasses, particularly miscanthus, have low fertilizer demands as compared to agricultural crops and the woody lignocellulosic feedstocks species. This is due to greater nutrient use efficiency and the capacity to recycle large amounts of nutrients into the rhizomes during the latter part of the growing season, which are then re-used for producing new shoots.

Woody lignocellulosic feedstocks

Short-term rotation coppice (SRC) of trees such as willow, poplar, and eucalypt is a widespread technology popular with energy producers. Willow and poplar are especially suited for temperate climate conditions while eucalypt species are adapted to subtropical and tropical climatic conditions.

Characteristics of miscanthus, switchgrass and reed canary grass Box A7-1

Miscanthus has high yield potential for cellulose fiber production. Its extensive underground rhizome system is a storage organ for nutrients and forms shoots every year. From the second season onwards miscanthus grows to a height of 2.5–3.5 m. Miscanthus can be grown on a wide range of soils from sandy to clay soils also on peat soils. Miscanthus does not tolerate prolonged dry periods or periods with stagnant water. Miscanthus biophysical requirements are similar to those for maize.

Reed canary grass occurs from wet to dry habitats and performs best on fertile and moist soils. It tolerates poorly drained conditions and flooding and is saline tolerant. Although it grows most vigorously on wet sites, it can survive dry conditions. Reed canary grass can be characterized as a sod forming perennial wetland grass with a production cycle between 10–15 years without new establishment.

Switchgrass, native to North America, grows well on a wide variety of soils ranging from sand to clay. Best are well-drained soils of low to medium fertility. pH should be above 6.5 for optimum yields but switchgrass can tolerate pH as low as 4.9. There are two distinct ecotypes; upland ecotypes, which are less productive than the lowland ecotypes, but can be used in cooler environments and are more tolerant to drought. Lowland ecotypes are taller, have thicker stems, and are more resistant to problems like rust than the upland types. Switchgrass, which can grow up to 3 m in height and has a lifespan is more than 10 years

Characteristics poplar, willow, and eucalypt. Box A7 - 2

Many poplar cultivars are in existence and are being used in different biophysical environments. In general, poplars require rather deep and fertile soils that are well drained with pH ranging from 5.5–8.5. Some poplars varieties tolerate short periods of waterlogging and flooding.

Willows also have rather high fertility requirements as well as deep soils. However, willow tolerates substantial periods of waterlogging, high groundwater tables, and flooding. This makes willow suitable for semi-wetland conditions.

Eucalypt is susceptible to frost, and has low water-use efficiencies (used to reclaim marshes and other wetland conditions). Soil requirements include moderately fertile and well drained water retentive soils. Eucalypt does not grow well on heavy clay soils, or soils with high calcium carbonate, but tolerates slight saline conditions. *Eucalyptus globulus*, the most widely grown eucalypt species is known to produce water-soluble toxins that may help prevent competition and reduces undergrowth. In contrast to willow and poplar, eucalypt stands are highly susceptible to fire in the dry season.

The global assessment of potentials for lignocellulosic feedstocks is based on the six woody and herbaceous species discussed above. However, in an ecological sense, these species cover temperate and subtropical conditions, with tropical conditions less well represented. *Ad interim*, while developing models for typical tropical woody and herbaceous feedstocks, use has been made of standard assessment methods for assessing net primary production. The latter calculations have, however, been embedded in the AEZ framework to enable the use of consistent AEZ biophysical data inventories consisting of high spatial and temporal resolution.

Results of the analysis are presented in a global suitability map for rain-fed lignocellulosic feedstocks (Figure A8-1). The suitability classification presented in this map includes an assessment of Net Primary Production (NPP) for tropical areas.

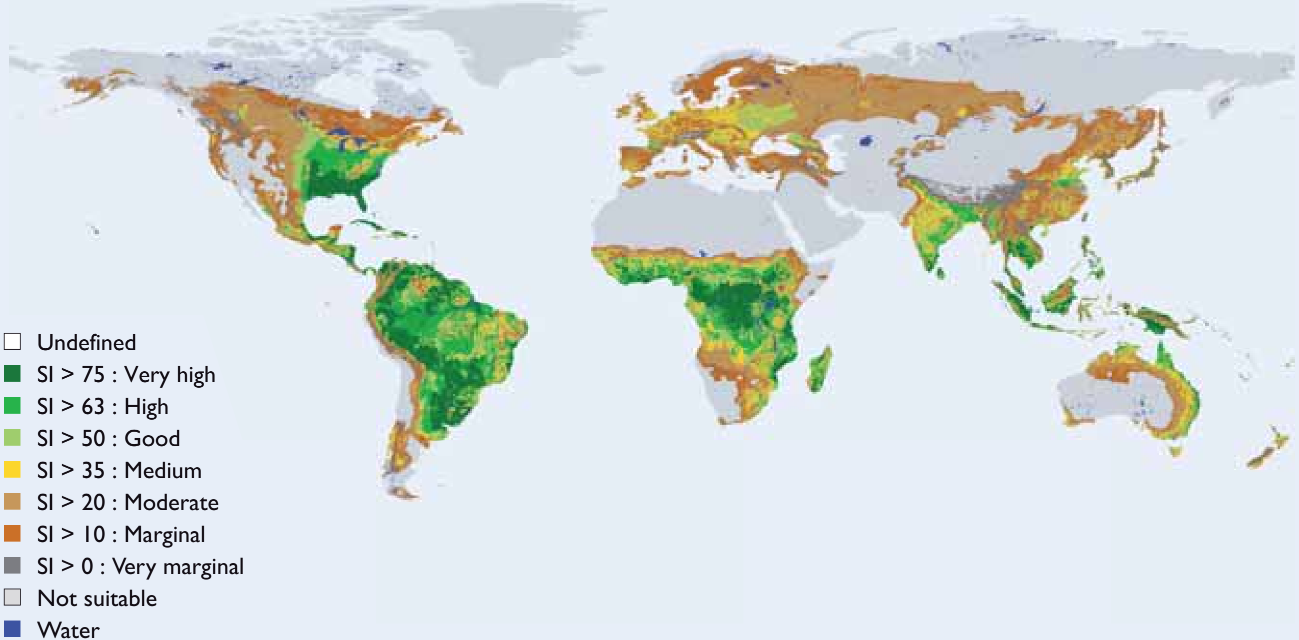
Highest potentials are found in humid tropical areas. In these areas the number of growing days is optimal as well as temperature and moisture regimes. However radiation regimes and soil fertility are generally better in dry areas and temperate zones.

Table A8-1 presents the rather theoretical case of suitability of currently cultivated land for lignocellulosic feedstocks. Due to better overall conditions in tropical areas, the share of land very suitable or suitable in developing countries is near 50 percent while in the dominantly temperate and subtropical developed countries the share is only 20 percent

Unprotected grassland and woodland have substantial potentials, in particular in Africa, with 238 million hectares, and in South America, with 241 million hectares (Table A8-2). Very suitable, suitable and moderately suitable extents of unprotected grassland and woodland amount to 860 million hectares of which 85 percent are found in developing countries. Even more suitable land can be found in unprotected forestland (Table A8-3), particularly in Brazil, with a high very suitable and suitable share of its vast unprotected forestland resources (more than 60 percent).

Global suitability for rain-fed lignocellulosic feedstocks

Figure A8



Fischer et al., 2008a.

Suitability of cultivated land for rain-fed lignocellulosic feedstocks

Table A8 - I

REGIONS *(Land: Mha)*	CULTIVATED LAND	POTENTIALLY SUITABLE LAND Very- and Suitable	POTENTIALLY SUITABLE LAND Moderately Suitable
North America	230	104	43
Europe & Russia	305	4	123
Oceania & Polynesia	53	9	10
Asia	559	210	132
Africa	244	125	50
Central America	43	32	5
South America	129	109	12
Developed	591	116	178
Developing	972	476	196
World	1563	592	374
United States	179	104	33
India	167	66	71
Brazil	66	60	4
China	139	42	40
Indonesia	35	32	1
Argentina	29	23	4
Nigeria	35	19	6
EU27	128	10	71

Source: Fischer et al., 2008a.

Suitability of grassland/woodland for rain-fed lignocellulosic feedstocks Table A8 - 2

REGIONS	UNPROTECTED GRASSLAND AND WOODLAND	POTENTIALLY SUITABLE LAND	
(Land: Mha)		Very- and Suitable	Moderately Suitable
North America	452	11	19
Europe & Russia	459	0	17
Oceania & Polynesia	496	34	46
Asia	511	18	15
Africa	878	238	118
Central America	71	9	8
South America	541	241	85
Developed	1400	41	82
Developing	2007	510	225
World	3408	551	308
Brazil	226	137	43
Argentina	163	37	29
Sudan	98	35	15
Australia	479	29	42
Madagascar	38	24	6
Mozambique	39	21	10
Tanzania	33	20	6
Congo, Dem. R.	26	20	6

Source: Fischer et al., 2008a.

Suitability of forest land for rain-fed lignocellulosic feedstocks Table A8 - 3

REGIONS	UNPROTECTED FOREST	POTENTIALLY SUITABLE LAND	
(Land: Mha)		Very- and Suitable	Moderately Suitable
North America	434	82	34
Europe & Russia	819	1	23
Oceania & Polynesia	98	40	18
Asia	394	81	46
Africa	362	232	61
Central America	69	19	9
South America	629	468	67
Developed	1341	108	74
Developing	1465	814	183
World	2806	922	257
Brazil	378	290	40
Congo, Dem. R.	130	112	14
United States	175	82	25
Peru	54	43	1
Indonesia	74	40	8
Bolivia	42	36	2
Colombia	44	29	6
Australia	64	24	15

Source: Fischer et al., 2008a.

References

Buarque de Hollanda, J. and A.D. Poole (2001). *Sugar cane as an energy source in Brazil. Rio de Janeiro, Brazil*, Instituto Nacional de Eficiência Energética.

Buckland, H. (2005) *The Oil for Ape Scandal: How Palm Oil Is Threatening Orang-Utan Survival*, Friends of the Earth, The Ape Alliance, The Borneo Orangutan Survival Foundation, The Orangutan Foundation (UK) and the Sumatran Orangutan Society.

Colchester, M., N. Jiwan, et al. (2006). *Promised Land. Palm Oil and Land Acquisition in Indonesia: Implications for Local Communities and Indigenous Peoples.* Executive Summary. http://mekongdmp.net/data/Resourcespapers/filepdf/PromisedLand.pdf.

Commissie Cramer, (2007). *Criteria for sustainable biomass production*. Available at: http://www.mvo.nl/biobrandstoffen/download/070427-Cramer-FinalReport_EN.pdf, accessed January 2009.

Conab (2008). *Companhia Nacional de Abastecimento.* Séries Históricas. http://www.conab.gov.br."

CONCAWE, EUCAR, JRC (2006). Well-to-wheels analysis of future automotive fuels and powertrains in the European context, WELL-to-WHEELS report, Version 2b; May 2006.

Corley, R.H.V. and P.B. Tinker (2003). *The Oil Palm*, Blackwell Science.

Crutzen P.J., Mosier A.R., Smith K.A. & Winiwarter W. (2008) *N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels.* Atmospheric Chemistry and Physics **8**: 389-395.

EBIO (European Biodiesel Board) (2008). Statistics. The EU Biodiesel Industry. Available at: http://www.ebb-eu.org/stats.php and http://www.ebb-eu.org/EBBpressreleases/EBB%20Brochure%20FINAL%2025.07.08.pdf, accessed January 2009.

EC (European Commission) (2008): Proposal for a directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, COM(2008) 19 final, January 2008.

EC DG AGRI (European Commission Directorate General Agriculture and Rural Development) (2008). *Bioenery and the CAP*. Available at: http://ec.europa.eu/agriculture/bioenergy/index_en.htm, accessed January 2009

EDC (2000). *Global Land Cover Charateristics Database version.2.0* (http://edcwww.cr.usgs.gov).

Elia Neto, A. (2008). *Água na indústria da Cana-de-açúcar.* In: Workshop Projeto PPP: Apecto ambientais da Cadeia do etanol de cana-de- açúcar, Painel I, Sao Paulo.

Euler, H. and D. Gorritz (2004). Case study on Jatropha curcas. Study commissioned by the Global Facilitation Unit for Underutilized Species (GFU) and the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

EurObserv'ER (2008). Biofuels Barometer. 7.7 consumed in EU in 2007. Available at: http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro185.pdf, accessed in December 2008.

Eurostat (2008): Agricultural statistics: Main results 2006/2007. Available at: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ED-08-001/EN/KS-ED-08-001-EN.PDF

Faaij, A., Alfred Szwarc and Arnaldo Walter (2008). *Demand for bioethanol for transport.* In: Zuurbier and van de Vooren (eds.) (2008). Sugarcane ethanol: Contributions to climate change mitigation and the environment. Wageningen Academic Publishers, ISBN 978-90-8686-090-6.

FAO (Food and Agriculture Organization of the United Nations) (2008a). The State of Food and Agriculture. *Biofuels: prospects, risks and opportunities*. FAO, Rome. 138 p.

FAO (2008b). The State of Food Insecurity in the World, 2008. Food and Agriculture Organization of the United Nations, Rome, Italy [ISBN 978-92-5-106049-0].

FAO/IIASA/ISRIC/ISSCAS/JRC (2008). *Harmonized World Soil Database (version 1.0)*. FAO, Rome, Italy and IIASA, Laxenburg, Austria.

FAO (2007). *Recent trends in the law and policy of bioenergy production, promotion and use.* FAO Legislative Study No. 95. Rome.

FAO (2006). *Global forest resources assessment 2005. Progress towards sustainable forest management.* Food and Agriculture Organization of the United Nations, Rome, Italy [ISBN 92-5-105481-9].

FAO (2005). *Global Forest Resources Assessment 2005*. FAO Forestry Paper 147. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2003). *World agriculture: towards 2015/2030.* An FAO perspective, edited by J. Bruinsma. Rome, FAO and London, Earthscan.

FAO (2001a). Global Forest Resources Assessment 2000, FAO, Rome, Italy.

FAO (2001b). The State of Food Insecurity in the World, 2001. Food and Agriculture Organization of the United Nations, Rome, Italy [ISBN 92-5-104628-X].

FAOSTAT (Time-series and cross sectional data relating to food and agriculture). FAO. Rome. Available at: http://faostat.fao.org/default.aspx.

Fargione, J., J. Hill, D. Tilman, S. Polasky and P. Hawthorne (2008). *Land clearing and the biofuel carbon debt.* Sciencexpress, 7 February.

Feed Mix Magazin (2006): *By-products for livestock feeding*. Feed Mix Vol.**14** No.6 http://www.allaboutfeed.net/raw_materials/id795/by-products.html

Fearnside, P.M. (2005). *Deforestation in Brazilian Amazonia: History, rates, and Consequences.* Conservation Biology **19**(3): 680-688.

Fischer, G., F. Nachtergaele, S. Prieler, E.Teixeira, H.T. van Velthuizen, L. Verelst, D. Wiberg, (2008a). *Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008)*. IIASA, Laxenburg, Austria and FAO, Rome, Italy.

Fischer, G., E. Teixeira, E Tothne-Hizsnyik and H. van Velthuizen (2008b). *Land use dynamics and sugarcane production.* In: Sugarcane ethanol, Contributions to climate change mitigation and the environment. Edited by Peter Zuurbier and Jos van de Vooren, Wageningen Academic Publishers, ISBN 978-90-8686-090-6. Also available as IIASA RP-09-001, IIASA, Laxenburg, Austria.

Fischer, G., F.N. Tubiello, H. van Velthuizen, D. Wiberg (2006). *Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080*. Technological Forecasting & Social Change, doi:10.1016/j.techfore.2006.05.021.

Fischer, G., M. Shah, F.N. Tubiello, H van Velhuizen (2005). *Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080*. Phil. Trans. Royal Soc. B, doi:10.1098/rstb.2005.1744.

Fischer G., H. van Velthuizen, M. Shah, F.O. Nachtergaele (2002a). *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results.* IIASA RR-02-02, IIASA, Laxenburg, Austria.

Fischer, G., M. Shah and H. van Velthuizen (2002b). *Climate Change and Agricultural Vulnerability*. Special Report as contribution to the World Summit on Sustainable Development, Johannesburg 2002. International Institute for Applied Systems Analysis, Laxenburg, Austria. pp 152.

Fischer G., K. Frohberg, M.A. Keyzer, K.S. Parikh (1988). *Linked National Models: a Tool for International Policy Analysis*. Kluwer Academic Publishers, 214pp.

Fischer, G., K. Frohberg, M.L. Parry, and C.Rosenzweig (1994). *Climate Change and World Food Supply, Demand and Trade: Who Benefits, Who Loses?* In: Global Environmental Change **4**(1), 7–23.

Fitzherbert, E.B., M.J. Struebig, et al. (2008). *How will oil palm expansion affect biodiversity?* Trends in Ecology and Evolution **23**(10): 538.

de Fraiture, C., Giordano, M., Liao, Y. Biofuels and implications for agricultural water use: Blue impacts of green energy (2008) Water Policy, 10 (SUPPL. 1), pp. 67-81. doi: 10.2166/wp.2008.054.

de Fraiture, C., M. Giordano and L. Yongsong (2007). *Biofuels and implications for agricultural water use: blue impacts of green energy*. Paper presented at the International Conference on Linkages between Energy and Water Management for Agriculture in Developing Countries. ICRISAT Camput, Hyderabad, India, 29-30 January 2007. Colombo, International Water Management Institute.

Fritsche, U.R. and K. Wiegmann (2008). *Ökobilanzierung der Umweltauswirkungen von Bioenergie-Konversionspfaden.* Expertise für das WBGU-Hauptgutachten „Welt im Wandel – Bioenergie und nachhaltige Landnutzung". http://www.wbgu.de/wbgu_jp2008_ex04.pdf Berlin.

GBEP (Global Bioenergy Partnership). 2007. *A review of the current state of bioenergy development in G8+5 countries*. Rome, GBEP Secretariat, FAO.

Goldemberg, J., S.T. Coelho and P. Guardabassi (2008). *The sustainability of ethanol production from sugarcane.* Energy Policy **36**(6): 2086-2097.

GSI (Global Subsidies Initiative) (2008). *Biofuels - At What Cost? Government support for ethanol and biodiesel in China.* International Institute for Sustainable Development. Winnipeg. Available at: http://www.globalsubsidies.org/files/assets/China_Biofuels_Subsidies.pdf, accessed January 2009.

Gunkel, G., J. Kosmol, M. Sobral, H. Rohn, S. Montenegro and J. Aureliano (2007). *Sugar Cane Industry as a Source of Water Pollution - Case Study on the Situation in Ipojuca River, Pernambuco, Brazil.* Water Air Soil Pollution **180**: 261-269.

Hamelinck, C. and A.P.C. Faaij (2006) *Production of advanced biofuels,* International Sugar Journal, 2006, Vol. **108** (1287), pp. 168-175.

Hamelinck, C.N., van Hooijdonk G., Faaij A.P.C. (2005). *Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-and long-term.* Biomass and Bioenergy 28, pp. 384–410.

Henson, I.E. and Chang, K.C. (2003). *Oil palm plantations and forest loss – an objective appraisal.* In: Proceedings of the PIPOC 2003 International Palm Oil Congress, pp. 960-974, Malaysian Palm Oil Board.

IEA (International Energy Agency) (2008a). *World Energy Outlook 2008*. OECD/IEA. Paris. 578 p.

IEA (International Energy Agency) (2008b). From 1st- to 2nd-generation biofuel technologies. An overview of current industry and RD&D activities. OECD/IEA, November 2008 (available as free download from www.iea.org).

IEA (International Energy Agency) (2007). *World Energy Outlook 2007*. China and India Insights. OECD/IEA. Paris. 674 p.

IEA (International Energy Agency) (2006). *World Energy Outlook 2006* Paris.

IFPRI (2002). *Global agricultural extent: Reinterpretation of global land cover characteristics database (GLCCD v. 2.0)*, EROS data center (EDC), 2000. International Food Policy Research Institute, Washington DC.

ISTA Mielke GmbH (2008). Oil World statistics. Available at: http://www.oilworld.biz/app.php, accessed November 2008.

IWMI (International Water Management Institute) (2008). Water implications of biofuel crops: understanding trades and identifying options. Water Policy Brief. Issue 30. Colombo. Available at: http://www.iwmi.cgiar.org/Publications/Water_Policy_Briefs/PDF/WPB30.pdf .

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Volume 4, IGES: Japan.

Jongschaap, R.E.E., W.J. Corré, P.S. Bindraban, and W.A. Brandenburg (2007). *Claims and facts on Jatropha curcas L.: global Jatropha curcas evaluation, breeding and propagation programme.* Report 158. Wageningen, Netherlands, Plant Research International.

Laurance, W.F. (2007). *Forest destruction in tropical Asia.* Curr. Sci. **93**, pp. 1544–1550. View Record in Scopus | Cited By in Scopus (3)

Lebbin, (2000). *Conservation crisis in Indonesia*. A Graduation with Distinction Paper. Environmental Science and Policy, Duke University. Quoted in: Clay, 2004.

Lewandowski I., Scurlock J.M.O., Lindvall E. and Christou M. (2003). The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass and Bioenergy 25, 335–361.

Licht, F.O. (Licht Interactive Data) (2008). *World Ethanol and Biofuels Report*, May 5, 2008

Licht, F.O. (Licht Interactive Data) (2007). *World Ethanol and Biofuels Report,* Oct 23, 2007

Macedo, I.C., J.E.A. Seabra and J.E.A.R. Silva (2008). *Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020*. Biomass and Bioenergy **32**(7): 582-595.

Martinelli, L. A. and S. Filoso (2008). *Expansion of sugarcane ethanol production in Brazil: environmental and social challenges.* Ecological Applications **18**(4): 885-898.

McCornick, P.G., S.B. Awulachew and M. Abebe (2008). *Water-food-energy-environment synegies and tradeoffs: Major issues and case studies*. In: Water Policy Volume 10 Supplement (2008).

McLaughlin, S., J. Bouton, D. Bransby, B. Conger, W. Ocumpaugh, D. Parrish, C. Taliaferro, K. Vogel, and S. Wullschleger (1999). *Developing switchgrass as a bioenergy crop*. p. 282–299. In: J. Janick (ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria, VA. Online at: http://www.hort.purdue.edu/newcrop/proceedings1999/v4-282.html.

Mitchell, T.D. and Jones P.D. (2005). *An improved method of constructing a database of monthly climate observations and associated high resolution grids.* Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK.

Mittelbach M., *Innovative Biofuels Feedstock.* 2nd National IEA Bioenergy Task 39 Liquid Biofuels Workshop. 9 September 2008, Vienna. Available at: http://www.abc-energy.at/pdfs/iea_workshop/Mittelbach.pdf, accessed January 2009.

Nakicenovic N., R. Swart (Eds.) (2000). *Special Report on Emissions Scenarios*, Intergovernmental Panel on Climate Change, Cambridge University Press, p. 570.

New, M., D. Lister, M. Hulme and I. Makin (2002). *A high-resolution data set of surface climate over global land areas.* Climate Research **21**

Pelkmans L., K. Kessels and L.Govaerts (2008). *Inventory of biofuel policy measures and their impact on the market.* Report D2.1 of ELOBIO subtasks 2.1-2.2. VITO Belgium.

Pelkmans L., E. Portouli, A. Papageorgiou and P. Georgopoulos (2006). *Impact assessment of measures towards the introduction of biofuels in the European Union,* PREMIA report, VITO, Belgium, September 2006.

REFUEL (2008). *Eyes on the track, mind on the road. From inconvenient rapeseed to clean wood: A European road map for biofuels*, online available at http://www.refuel.eu/fileadmin/refuel/user/docs/REFUEL_final_road_map.pdf

Renewable Fuels Association (RFA) (2008a). *Ethanol Industry Statistics*. Available at: http://www.ethanolrfa.org/industry/statistics/, accessed in December 2008

Renewable Fuels Association (RFA) (2008b). *Biofuel co-products.* Available at: http://www.ethanolrfa.org/industry/resources/coproducts, accessed in December 2008

Riahi, K., A. Gruebler and N. Nakicenovic (2006). *Scenarios of long-term socio-economic and environmental development under climate stabilization.* Technological Forecasting & Social Change. doi:10.1016/j.techfore.2006.05.026.

Robertson, G.P., V.H. Dale, O.C. Doering, S.P. Hamburg, J.M. Melillo, M.M. Wander, W.J.Parton, W.W. Wilhelm (2008). *Agriculture: Sustainable biofuels redux.* Science, **322** (5898), pp. 49-50. doi: 10.1126/science.1161525

Rosenzweig, C. and M.L. Parry, (1994). *Impacts of Climate Change on World Food Supply*. Nature **367**, 133–138.

The Royal Society (2008). *Sustainable Biofuels: Prospects and Challenges*. Clyvedon Press Ltd, UK, ISBN 978 085403 662 2

Scharlemann, J.P.W. and W.F. Laurance (2008). *Environmental Science: How Green Are Biofuels?* Science **319**(5859): 43-44.

Schmidt, J.H. and B.P. Weidema (2007). *Shift in the marginal supply of vegetable oil.* International Journal of Life Cycle Assessment **13**(3), pp. 235-239.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes and T. Yu (2008). *Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change.* Sciencexpress, 7 February.

Searchinger, T. 2008. *The impacts of biofuels on greenhouse gases: how land use change alters the equation.* Policy Brief. Washington, DC, The German Marshall Fund of the United States.

Shah, M., (Coordinating Lead Author) et al. (2005). *Millennium Ecosystems Assessment, Ecosystems and Human Well-being.* Volume 3 Policy Responses, Chapter 5 – *Food and Ecosystems*, pp 175-212. Island press, ISBN-1-55963-269-0, 2005

Shah, M. (Coordinating Author) (1992) *The Global Partnership for Environment and Development - A Guide to Agenda 21*. Earth Summit Report, The United Nations Press, New York, June 1992

Silvius, Marcel, Alex Kaat and Helen van de Bund (2006). *Peatland degradation fuels climate change.* Wetlands International. The Netherlands.

Singh, S. (2007). *India Bio-fuels Annual 2007, Gain Report,* New Delhi. The Energy and Resources Institute (TERI) (2007), Vulnerability to Climate Variability and Change in India: Assessment of Adaptation Issues and Options, TERI, New Delhi.

Smeets, E., M. Junginger, A. Faaij, A. Walter, P. Dolzan and W. Turkenburg (2008). *The sustainability of Brazilian ethanol – An assessment of the possibilities of certified production.* Biomass and Bioenergy **32**(8): 781-813.

Sodhi, N.S. and B.W. Brook (2006). *Southeast Asian Biodiversity in Crisis.* Cambridge University Press

Sodhi, N.S., *et al.* (2004). *Southeast Asian biodiversity: an impending disaster, Trends.* Ecol. Evol. **19** pp. 654–660. Article | PDF (407 K) | View Record in Scopus | Cited in Scopus (78)

Steenblick, R. (2007). *Biofuels – At What Cost? Government support for ethanol and biodiesel in selected OECD countries.* International Institute for Sustainable Development. Geneva.

Tan, K.T., K.T. Lee, A.R. Mohamed, S. Bhatia (2009). *Palm Oil: Addressing issues and towards sustainable development.* Renewable and Sustainable Energy Reviews 13 (2009) 420-427 and ScienceDirect www.sciencedirect.com

Tubiello, F.N., G. Fischer (2006). *Reducing climate change impacts on agriculture: Global and regional effects of mitigation, 2000–2080.* Technological Forecasting & Social Change (2006), doi:10.1016/j.techfore.2006.05.027.

United States Department of Agriculture (USDA) (2008a). Farm Bill. http://www.usda.gov/wps/portal/farmbill2008?navid=FARMBILL2008

USDA FAS (2008b). Oilseeds: World Market and Trade: http://www.fas.usda.gov/oilseeds/circular/2005/05-10/octcov.pdf

USDA (2008c). Trostle, R., *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices.* USDA, May 2008.

USDA (2007). Indonesia: Palm Oil Production Prospects Continue to Grow. Available at: http://www.pecad.fas.usda.gov/highlights/2007/12/Indonesia_palmoil/ accessed February 2009.

USDA. (2006). *The Economic Feasibility of Ethanol Production from Sugar in the United States.* Available at: http://www.usda.gov/oce/reports/energy/EthanolSugarFeasibilityReport3.pdf , accessed January 2009.

Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU) (2008) *Welt im Wandel – Zukunftsfähige Bioenergie und nachhaltige Landnutzung*. http://www.wbgu.de Berlin, Germany.

Worldwatch Institute (2007). *Biofuels for transport. Global potential and implications for sustainable energy and agriculture*. Earthscan, London, UK, ISBN: 978-84407-422-8.

Zah, R., H. Böni, M. Gauch, R. Hischier, M. Lehmann, and P.Wäger (2007). Ökobilanz von Energieprodukten: Ökologische Bewertung von Biotreibstoffen. St Gallen, Switzerland, EMPA www.empa.ch.

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